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AGING AND SURVEILLANCE TESTING OF AN AEROJET MINUTEMAN LGM-30G STAGE III ROCKET MOTOR AT SIMULATED PRESSURE ALTITUDE (MOTOR S/N TMS-10)

C. H. Kunz and D. E. Franklin

ARO, Inc.

May 1973

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FOREWORD

The work reported herein was conducted by the Arnold Engineering Development Center (AEDC) at the request of the Space and Missile Systems Organization (SAMSO), Air Force Systems Command (AFSC), for the Thiokol Chemical Corporation under Program Element 11213F, System 133B.

The results of the test were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the AEDC, AFSC, Arnold Air Force Station, Tennessee. The test was conducted on March 8, 1973, under ARO Project No. RA203, and the manuscript was submitted for publication on April 9, 1973. The ARO Project Engineer was Mr. D. E. Franklin.

This technical report has been reviewed and is approved.

CHAUNCEY D. SMITH, JR.
Lt Colonel, USAF
Chief Air Force Test Director, ETF
Directorate of Test

A. L. COAPMAN
Colonel, USAF
Director of Test

ABSTRACT

An LGM-30G Stage III solid-propellant rocket motor, designated TMS-10 (aged 42 months), was fired in Rocket Development Test Cell (J-5), Engine Test Facility (ETF), in support of the Minuteman III Stage III Aging and Surveillance (A&S) Test Program on March 8, 1973. There was an apparent insulator/grain separation 10 sec after motor ignition as indicated by chamber pressure and linear potentiometers located on the motor aft dome and nozzle mounting flange. Vacuum thrust attained upper specification limits from 18 to 28 sec after motor ignition and was below specification limits from 46 to 54 sec. Motor ballistic, liquid-injection thrust vector control system, roll control, and thrust termination system performance was within model specification requirements. Ignition of the roll control gas generator and the liquid-injection thrust vector control isolation valve squibs was accomplished, as programmed, 2.5 sec before motor ignition at a pressure altitude of 100,000 ft. The motor was ignited at a pressure altitude of 100,000 ft. Motor ignition delay time was 90 msec. Motor thrust termination occurred at 60.49 sec at a chamber pressure of 74.3 psia. The motor produced an unaugmented vacuum total impulse of 2,083,900 lbf-sec during action time. The unaugmented vacuum specific impulse was 284.01 lbf-sec/lbm. Maximum interstage pressure rise at thrust termination was within specification. Postfire motor structural integrity was satisfactory.

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APPENDIXES

SECTION I
INTRODUCTION

The objectives of the SAMSO Minuteman III Stage III Aging and Surveillance Program (Ref. 1) are to (1) determine the adverse effects of aging on motor performance, (2) generate test data from which the service life of the test article can be estimated, and (3) demonstrate that the motor service life specification requirements have been met. Thiokol Chemical Corporation (TCC), Wasatch Division, Brigham City, Utah, was selected to provide overall technical management for this test program by the sponsor, SAMSO (MMNP-B), Norton Air Force Base, California. The Aging and Surveillance Program includes operational and storage motors manufactured by the Aerojet Solid Propulsion Company (ASPC), (designated 52MS-X and AOP-X) and TCC (designated SUR-X and TOP-X). The March 8, 1973, test of motor TMS-10 (aged for 42 months) reported herein is the sixth in a series to be fired at AEDC and the fourth under AEDC Project No. RA203.

This motor was the first of a series of four especially selected to investigate relationships that were postulated to exist between propellant-to-insulator separations ("UNZIP") during firing and/or propellant voids and aft dome burnthrough failures. High priority testing of these motors was requested by SAMSO following a flight failure of a Stage III motor at Vandenburg AFB which was believed to be an aft dome burnthrough. Motor TMS-10 had 12.5 sq in. of projected void area located at 300 deg in the aft dome apex area.

SECTION II
APPARATUS

2.1 TEST ARTICLE DESCRIPTION

The LGM-30G Stage III Minuteman motor (Fig. 1, Appendix I) is comprised of a glass filament-wound chamber loaded with ANB-3066 solid propellant; a solid-propellant igniter with a safe-and-arm device; a single, partially submerged nozzle with a nominal expansion ratio of 22; a liquid-injection thrust vector control (LITVC) system; a hot gas roll control (RC) system; and a motor thrust termination system. Test article configuration and component serialization are presented in Table I (Appendix II). Nominal motor length and diameter are 92 and 52 in., respectively. The model specification (Ref. 2) establishes an upper limit on total motor mass of 8040 lbm and a minimum limit on loaded propellant mass of 7250 lbm. The motor nominally produces an average thrust of 34,000 lbf at an average motor chamber pressure of 500 psia for approximately 60 sec.

The liquid-injection thrust vector control system (Fig. 2) consists of two operative and two inactive electromechanical servoinjector valves, located at 90-deg intervals on the nozzle at an expansion ratio of 10.3; an injectant tank containing approximately 49.3 lbm of a 66-percent solution of strontium perchlorate injectant fluid; a squib-actuated isolation valve and pressure regulator assembly; a pressurant tank containing helium; and a launch limit pressure switch. The two inoperative valves, located at the 0- (target down)

and 180-deg positions, are used to blank off those injection ports and provide flight configuration hydraulic simulation. Injection in the pitch plane is not required to establish system conformance to specification.

The hot gas roll control system is mounted inside the forward skirt at an angular location of 22 deg. The system consists of a squib-actuated, solid-propellant gas generator and a shuttle valve with two opposed nozzles exhausting through the forward skirt.

The thrust termination system, located on the motor forward dome, consists of redundant squib initiators, completely contained redundant mild detonating fuses (CCMDF), linear-shaped charges, thrust termination stacks, stack bellows, and stack covers. The shaped charges, when activated, cut six circular holes in the forward dome, allowing the chamber to vent through the thrust termination stacks.

2.2 TEST CELL AND INSTALLATION

Rocket Development Test Cell (J-5) (Fig. 3 and Ref. 3) is a horizontal test complex for testing rocket motors with a maximum of 100,000-lbf thrust at pressure altitudes of approximately 100,000 ft. The cell is 16 ft in diameter and 50 ft long. The cell is equipped with a temperature-conditioning system designed to maintain the test cell and motor in a prescribed temperature range from motor installation until prefire pumpdown.

The multicomponent thrust stand utilized is capable of measuring axial forces of 100,000 lbf, and pitch and yaw forces of 6000 lbf. The thrust stand natural frequency for a fully loaded LGM-30G Stage III motor is approximately 27 Hz in the axial direction and 22 Hz in the yaw direction. A steam ejector-diffuser system is used in conjunction with rotating exhauster machinery to provide altitude simulation.

2.3 INSTRUMENTATION

The types of data acquisition and recording systems used during this test were a multiple-input digital data acquisition system scanning each parameter at a basic rate of 100 samples/sec (with selected parameters supercommutated to 1000 samples/sec) and recording on magnetic tape; single-input continuous recording system recording in pulse form on magnetic tape; frequency modulation (FM) systems recording on magnetic tape; and photographically recording galvanometer-type oscillographs. Motion-picture cameras operating at 200 frames/sec provided a permanent visual record of the firing. Table II presents a summary of motor instrumentation. Instrumentation calibration techniques are described in Appendix III. Uncertainties of the J-5 instrument systems are presented in Appendix IV. The digital data were reduced with an IBM 370/155 computer.

SECTION III
PROCEDURE

The motor arrived at AEDC on February 21, 1973. Significant motor inspection and handling records are presented as follows:

Date	Activity or Item Performed	Remarks
February 21, 1973	Motor arrived at AEDC; visual inspection performed	No anomalies noted
February 27, 1973	X-ray inspection completed; moved motor from X-ray Lab to Rocket Preparation Area	X-ray results met specifications
March 1, 1973	Roll control system leak check	Leak check satisfactory
March 1, 1973	Completed motor leak check	Leak check satisfactory
March 2, 1973	Injector valves 2 and 4 installed	
March 2, 1973	Completed electrical checks	
March 3, 1973	Completed installation of forward pylon and pressure checked	
March 5, 1973	Interstage volume leak check completed	Leak check satisfactory
March 5, 1973	Prefire nozzle measurements taken	Results in Table III
March 6, 1973	Motor transferred to test cell and installed; alignment completed	
March 6, 1973	Thrust vector control valve leak check completed	Leak check satisfactory
March 6, 1973	Thrust vector and roll control systems functional checkout completed	
March 7, 1973	Completed thrust vector control valve pintle calibrations	
March 8, 1973	Fired motor at 1654 hours	
March 8, 1973	Visual inspection performed	Motor condition satisfactory

Date	Activity or Item Performed	Remarks
March 8, 1973	Motor removed from test cell and transferred to Rocket Preparation Area	
March 9, 1973	Postfire nozzle measurements taken	Results in Table III
March 9, 1973	Motor shipped to TCC	

SECTION IV
RESULTS AND DISCUSSION

4.1 GENERAL

The results reported herein were obtained from the firing of an Aerojet LGM-30G Stage III motor, TMS-10 (aged 42 months), in Rocket Development Test Cell (J-5) on March 8, 1973. This was the sixth in a series of motors to be fired at AEDC as part of the SAMSO Minuteman LGM-30G Stage III Aging and Surveillance Program. The motor was temperature conditioned at 70 ± 5°F. Propellant grain temperature at the time of ignition was 72°F. A summary of storage and conditioning temperatures is presented in Table IV.

4.2 BALLISTIC PERFORMANCE

Motor ballistic performance for this motor was within the requirements of the applicable model specification except for unaugmented vacuum thrust. A summary of the performance data for this motor is presented in Table V. Data from this test are compared with data obtained from other tests of LGM-30G Stage III A&S motors fired at AEDC in Table VI. Histories of axial force, chamber pressure, and test cell pressure are presented in Fig. 4.

4.2.1 Motor Ignition

The motor was successfully ignited at a pressure altitude of 100,000 ft (geometric pressure altitude, Z, Ref. 4). Motor ignition current was within the specification limits of 4.5 to 4.9 amp. A history of igniter pressure during motor ignition is presented in Fig. 5. Igniter pressure was within specification limits.

Motor ignition delay (defined as the time from application of ignition voltage until 75 percent of the maximum chamber pressure attained during the first second of motor operation) was 90 msec. This was within the specification limit of 200 msec. Ignition delay versus age of this motor and other LGM-30G Stage III A&S motors fired at AEDC is presented in Fig. 6.

4.2.2 Combustion Chamber Pressure

Average combustion chamber pressure during motor action time was 518 psia. The maximum operating chamber pressure achieved during the firing was 703 psia at T + 21.980 sec.

Motor chamber pressure during motor operation is compared with predicted chamber pressure in Fig. 7. Predicted chamber pressure values were calculated using the following: (1) manufacturers' predicted vacuum thrust (Ref. 5), (2) a constant thrust coefficient of 1.74365 provided by telephone conversation with the motor manufacturer, and (3) throat area values supplied by TCC (Appendix V).

4.2.3 Axial Thrust

Unaugmented vacuum-corrected thrust is compared with the specification limits (Ref. 2) in Fig. 8. The specification envelope is applicable for motor conditioning temperatures from 60 to 80°F. Thrust data for motor TMS-10 (temperature conditioned at 72°F) attained upper specification limits from 18 to 28 sec after motor ignition and was below specification limits from 46 to 54 sec. Motor action time, defined as the time from the application of ignition voltage until 5000 lbf of vacuum thrust during motor tailoff, was 60.49 sec. This was within the specification limits of 58.20 to 63.14 sec for a motor with a propellant grain temperature of 72°F. An illustration of action time versus age for motor TMS-10 and other LGM-30G Stage III A&S motors fired at AEDC is presented in Fig. 9. Average unaugmented vacuum-corrected thrust during motor action time was 34,450 lbf. Average vacuum-corrected thrust for this motor is compared with other LGM-30G Stage III A&S motors fired at AEDC in Fig. 10.

The average thrust coefficient during motor action time, excluding thrust augmentation, was determined from vacuum-corrected total impulse, integral of motor chamber pressure, and an estimated history of throat area supplied by TCC. The average thrust coefficient calculated for this motor was 1.744.

4.2.4 Impulse

Measured total impulse during motor action time was 2,071,952 lbf-sec. Total impulse corrected to vacuum conditions was obtained by adding the product of the cell pressure integral and nozzle exit area to the measured total impulse. The nozzle exit area was calculated using an interpolative procedure based on a prefire measured exit area and a calculated postfire area (Appendix V). This vacuum correction was approximately 0.6 percent of the measured total impulse. The vacuum total impulse during action time, including thrust augmentation, was 2,084,608 lbf-sec. The vacuum total impulse, excluding augmentation, was 2,083,900 lbf-sec. The vacuum total impulse during action time, excluding thrust augmentation, is presented in Fig. 11 with data for other LGM-30G Stage III A&S motors fired at AEDC. The vacuum specific impulse for this motor, calculated using a total loaded propellant mass of 7337.4 lbm, was 284.01 lbf-sec/lbm, and was

within the specification limits of 283.1 to 286.1 lbf-sec/lbm. Specific impulse for this motor compares well with other LGM-30G Stage III A&S motors tested at AEDC as shown in Fig. 12. The specific impulse, calculated using the total propellant mass minus a TCC-supplied sliver weight of 23.0 lbm, was 284.90 lbf-sec/lbm.

4.2.5 Motor Propellant Flow Rate

Average exhaust gas mass flow rate during action time was 121.3 lbm/sec. The flow rate calculation was performed utilizing Equation 16 presented in Appendix V.

4.3 MOTOR VIBRATION

A history of the vibrations recorded by the standard accelerometer on the igniter boss (AIGN30Y) for the first 20 sec of motor operation is presented in Fig. 13. The maximum amplitude during this period were 18-g peak at T + 1 sec.

4.4 ROLL CONTROL AND LIQUID-INJECTION THRUST VECTOR CONTROL SYSTEMS PERFORMANCE

4.4.1 Roll Control System

The roll control gas generator was ignited, as programmed, 2.5 sec before motor ignition at a pressure altitude of 100,000 ft. A history of gas generator pressure during the test is compared to the model specification limits (Ref. 6) in Fig. 14. The roll control system duty cycle is shown in Table VII. All valve response times were within the model specification limits. A summary of system performance is included in Table VIII.

4.4.2 Liquid-Injection Thrust Vector Control System

The LITVC isolation valve squib was ignited successfully at a simulated pressure altitude of 100,000 ft, 2.5 sec prior to motor ignition. The launch limit pressure switch opened 5 msec after squib ignition. Thrust vector control delay time, defined as the time from application of isolation valve squib voltage until attainment of 655-psia pressure in the injectant manifold, was 1.272 sec. This was within the specification limits of 1.0 to 1.6 sec. Injectant manifold and regulated helium pressures are presented in Fig. 15. During periods of no flow, following the establishment of steady pressure in the injection manifold until thrust termination time, the injection manifold pressure varied from 675 to 688 psia. Manifold inlet pressure at slam suppressor pin shear was 461 psia.

The injector valves were operated per the duty cycle presented in Table IX. Histories of injector command voltage, injector feedback voltage, and injectant flow rate are presented in Fig. 16 for the two injectors which were operated during the firing. A compilation of thrust vector control performance parameters is presented in Table X.

A thrust vector angle of 2.24 deg was produced by an injectant flow rate of 10.2 lbm/sec during the time period from 3 to 4 sec. This met the requirement to demonstrate

a minimum 2-deg capability. The system performance during the nominal 1- and 2-lbm/sec flow rates was within the LITVC system gain specification as shown in Fig. 17.

4.5 THRUST TERMINATION

Thrust termination was initiated 60.49 sec after motor ignition at a chamber pressure of 74.3 psia. Breakwires on each of the six thrust termination ports indicated that the first port had been opened by 403 μsec after thrust termination signal application. The time from first port rupture to last port rupture was 105 μsec. This met the specification requirement of 219 to 705 μsec. No significant amount of fiberglass strands remained attached after the firing.

During the first 2 sec following thrust termination, the sealed dome interstage volume experienced a maximum pressure rise of 0.582 psi. This was within the established maximum limit of 0.925 psi for a motor thrust terminated at 75 psia.

4.6 STRUCTURAL INTEGRITY

Visual postfire inspection showed the motor to be in good condition (Fig. 18). There was a visual indication of a hairline crack (approximately one inch in length) on the arm/disarm inner mounting foot. Two CCMDF cables (one to stack 2 and one to stack 3) were expelled at the block manifold assembly. Two other fuses (to stacks 5 and 6) were partially ruptured at the manifold assembly. There were no hot spots on the external aft dome that could be visually detected. There were a few small areas (approximately 2 sq in.) on the internal aft dome where the insulator had burned through to the case.

4.7 AFT DOME PROPELLANT/INSULATOR SEPARATION STUDY

The motor was instrumented with potentiometers and strain gages on the case aft dome and potentiometers on the nozzle mounting flange (Fig. 19) to measure expansion and displacement of the motor chamber in a direction parallel to the thrust axis. These were installed to investigate a possible propellant/insulator separation in the apex area of the aft dome. Histories of the nozzle mounting flange and aft dome displacements throughout the firing are shown in Figs. 20 and 21, respectively. Histories of aft dome strain-gage data are presented in Fig. 22. Maximum deflections indicated were 0.85 in. at both the 20-deg and 235-deg locations on the nozzle mounting flange and 0.62 in. on the aft dome (near the nozzle mounting flange). A slope increase was observed in chamber pressure, potentiometer displacement data, and strain-gage data at approximately T + 10 sec indicating a possible propellant/insulator separation. Partial histories of typical nozzle flange and aft dome displacement, and aft dome strain-gage data are shown with chamber pressure in Fig. 23a. These are ratioed to chamber pressure in Fig. 23b.

SECTION V
SUMMARY OF RESULTS

The results of testing an Aerojet A&S Minuteman LGM-30G Stage III motor, TMS-10 (aged 42 months), at an average altitude of 92,000 ft are summarized as follows:

1. Vacuum thrust attained the upper specification limit from 18 to 28 sec after motor ignition and was below specification limits from 46 to 54 sec. Other motor ballistic, liquid-injection thrust vector control, roll control, and thrust termination system performance was within model specification requirements.

2. An increase in motor chamber pressure and aft end displacement, in a direction parallel to the axial-thrust axis (as indicated by linear potentiometers and strain gages), was noted approximately 10 sec after motor ignition. These data indicate that a possible propellant/insulator separation occurred at that time.

3. Visual postfire inspection showed the motor to be in good condition. There were a few small areas (approximately 2 sq in.) on the internal aft dome where the insulation had burned through to the case. There was a visual indication of a hairline crack (approximately one inch in length) on the arm/disarm device inner mounting foot. Two CCMDF cables were expelled at the block manifold assembly and two others were partially ruptured.

4. The motor was ignited at a pressure altitude of 100,000 ft, and the ignition delay was 98 msec.

5. Vacuum-corrected unaugmented total impulse was 2,083,900 lbf-sec during motor action time of 60.49 sec; vacuum specific impulse was 284.01 lbf-sec/lbm.

6. The thrust vector and roll control systems operated as programmed throughout the firing. Thrust vector control system gain and roll control response times met specification requirements.

7. Thrust termination was initiated 60.49 sec after motor ignition at a chamber pressure of 74.3 psia. The first thrust termination port was opened by 403 μsec after thrust termination signal application. The time from first port rupture to last port rupture was 105 μsec.

REFERENCES

1. "Minuteman Engineering Directive, Minuteman III, LGM-30G Stage III Motor Surveillance Program Requirements." 71-9, September 22, 1972.

2. "Appendix to Model Specification S-133-1003-0-4, Part II, Third Stage, QT Appendix." July 15, 1969.

3. Test Facilities Handbook (Ninth Edition). "Engine Test Facility, Vol. 2." Arnold Engineering Development Center, July 1971.

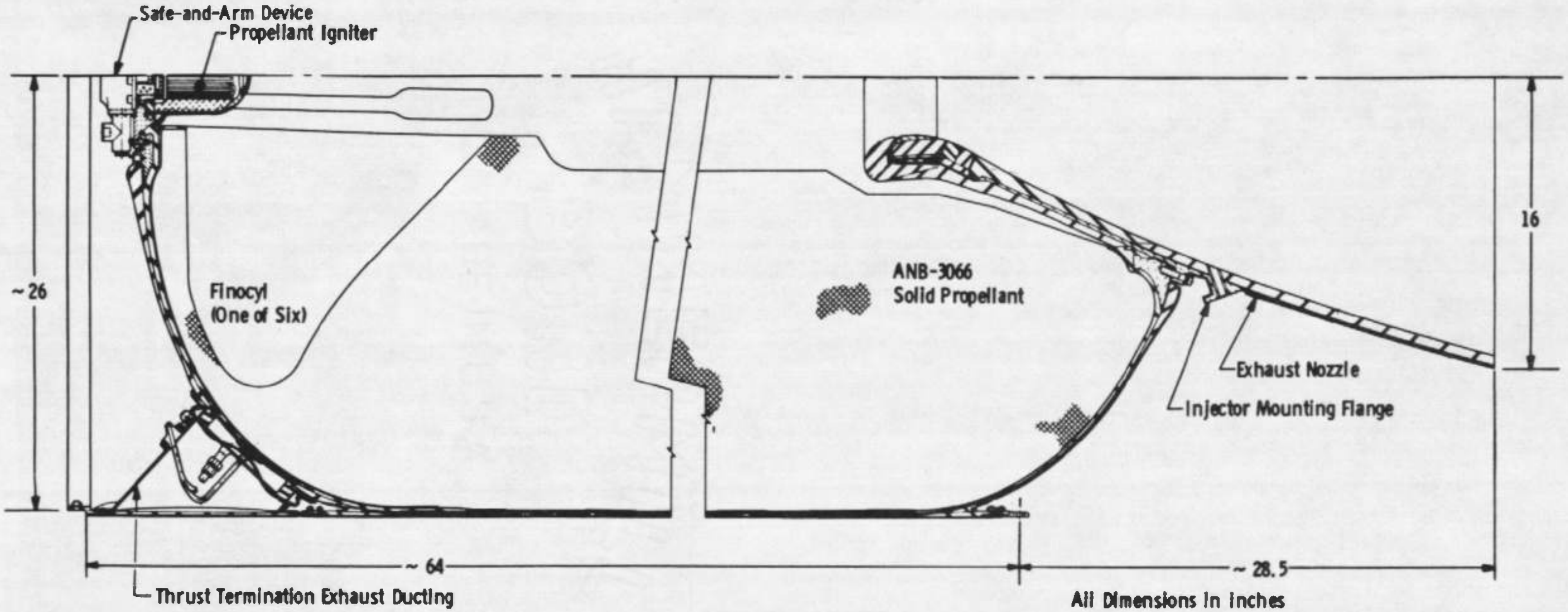
4. Dubin, M., Sissenwine, N., and Wexler, H. U.S. Standard Atmosphere, 1962. U.S. Government Printing Office, Washington, D.C., December 1962.

5. "Minuteman Stage III Rocket Motor Assembly Log, Motor TMS-10." Aerojet General Corporation. November 17, 1969.

6. "Model Specification S-133-1003-0-4, Part II, Production Configuration and Acceptance Test Requirements." September 30, 1971.

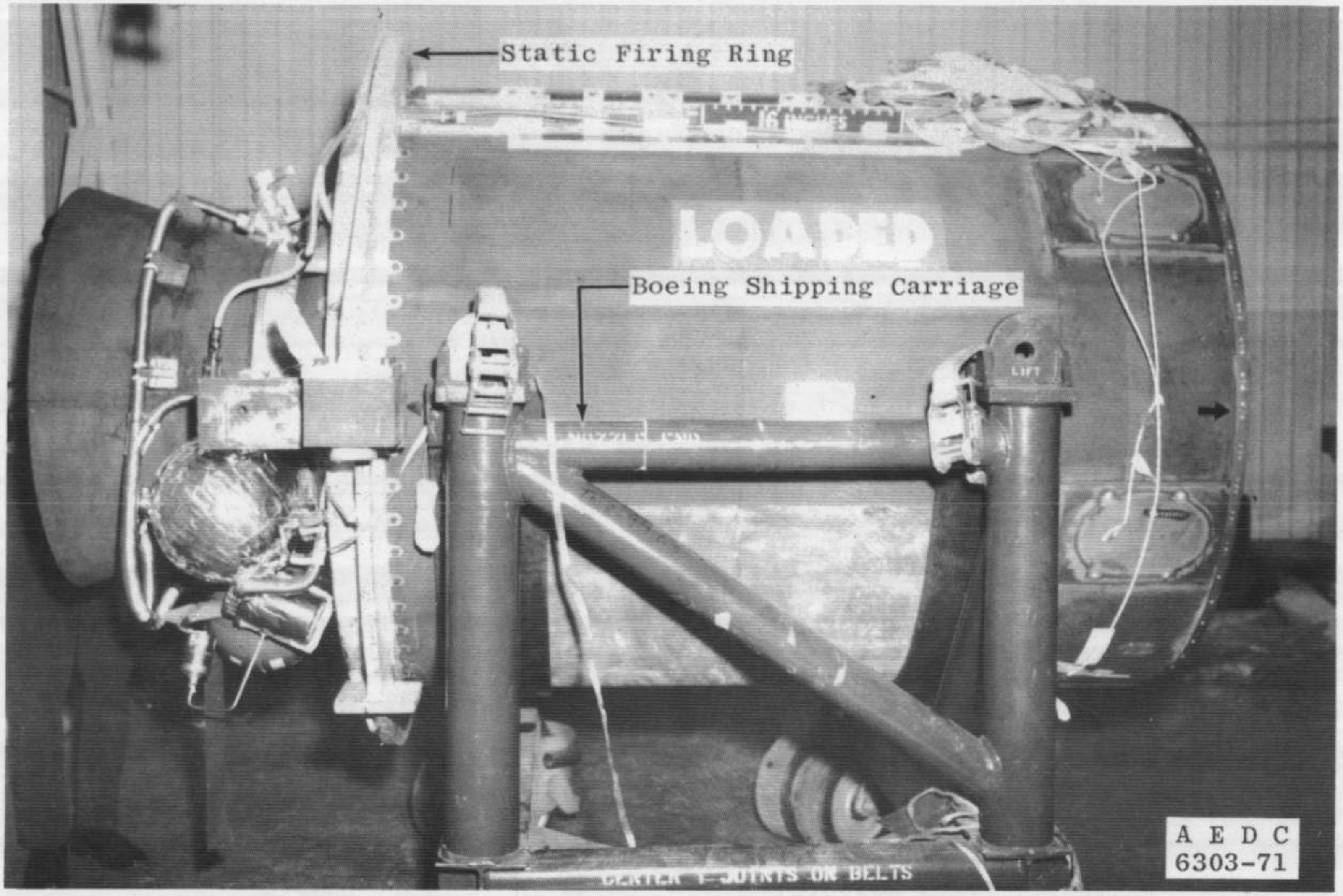
APPENDIXES

I. ILLUSTRATIONS
II. TABLES
III. INSTRUMENTATION CALIBRATIONS
IV. UNCERTAINTIES OF THE J-5 INSTRUMENT SYSTEMS
V. METHODS OF CALCULATION



a. Cutaway Schematic of Motor

Fig. 1 Minuteman LGM-30G Stage III Rocket Motor



b. Overall View
Fig. 1 Concluded

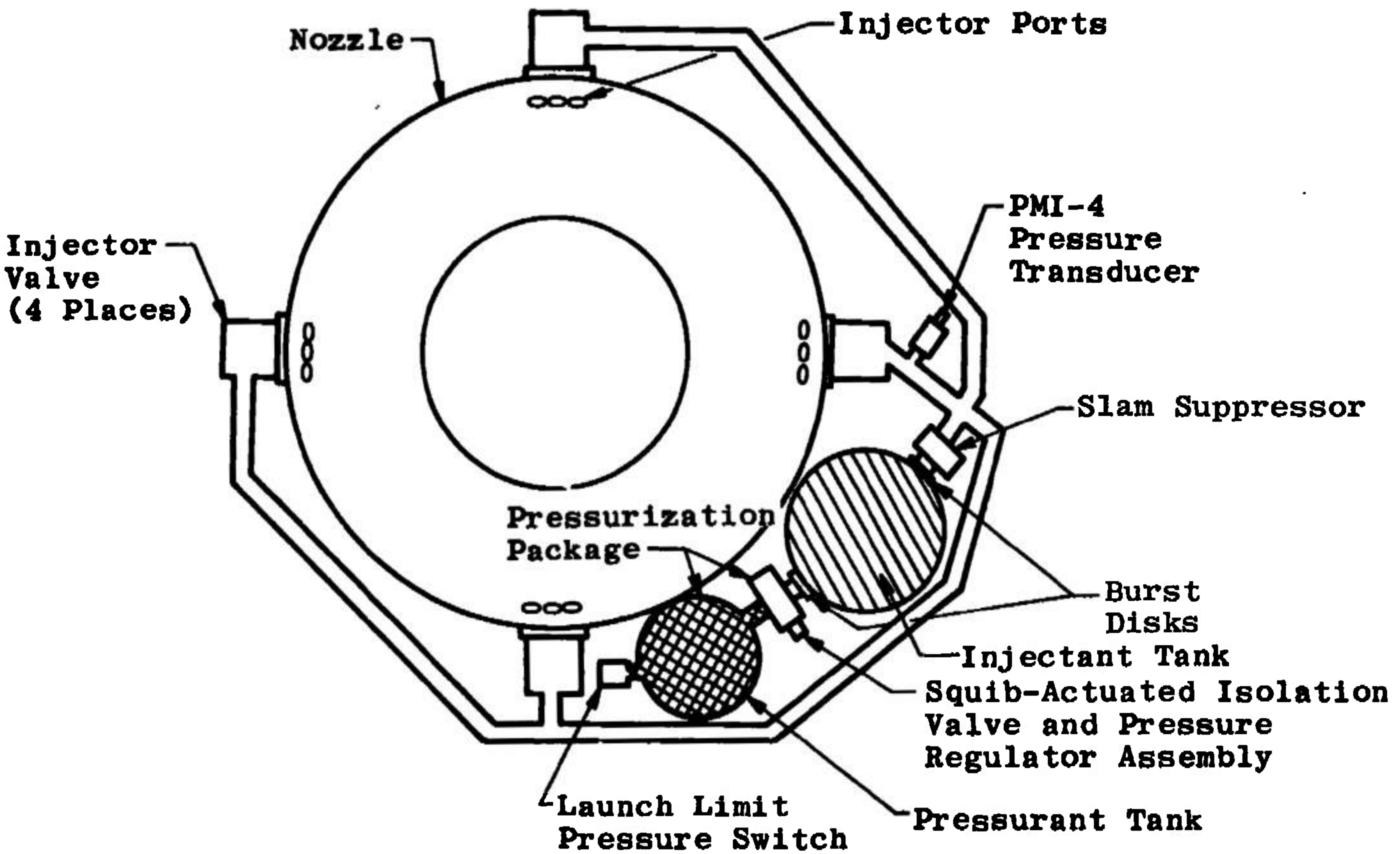


Fig. 2 Liquid-Injection Thrust Vector Control System Schematic

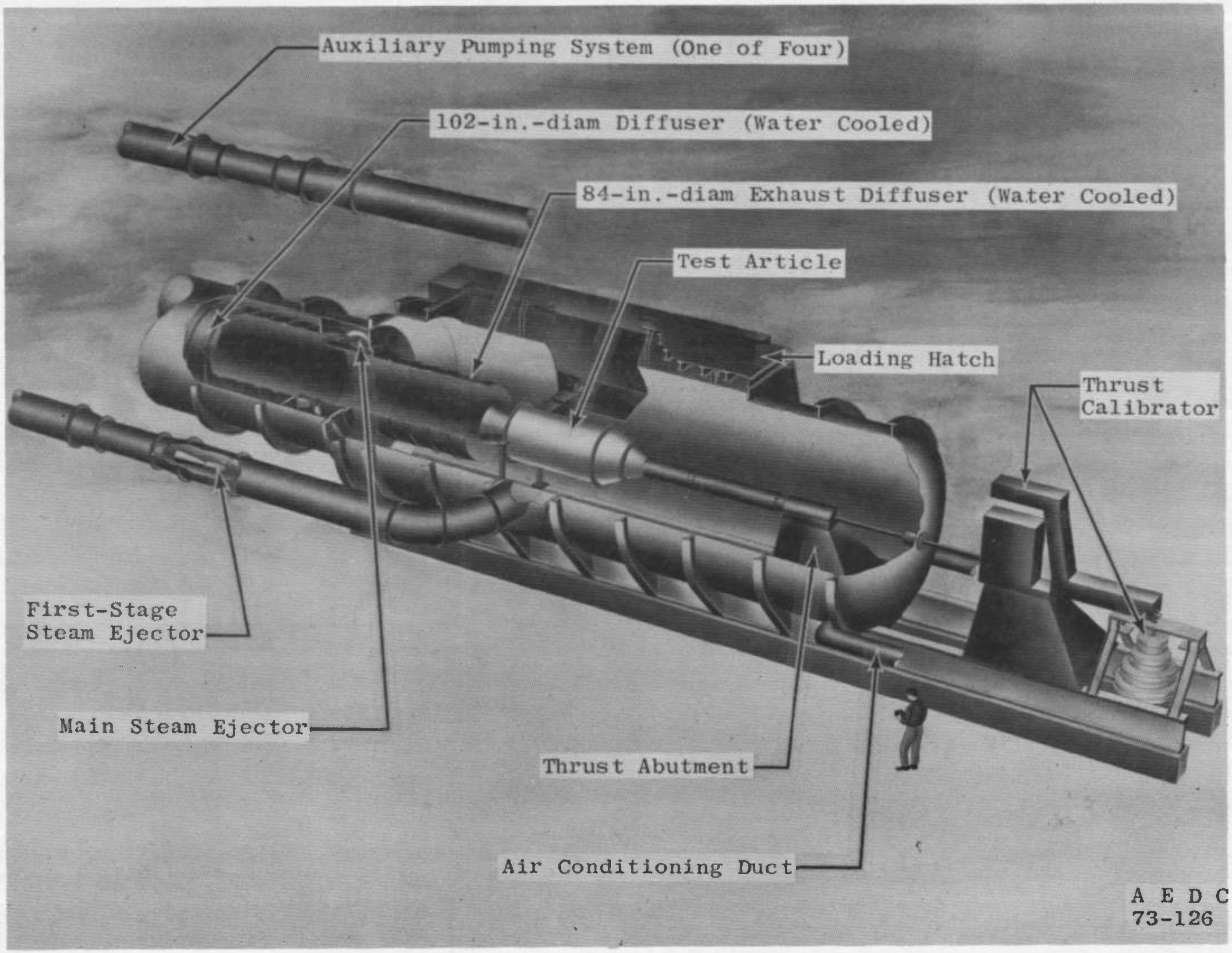


Fig. 3 Rocket Development Test Cell (J-5)

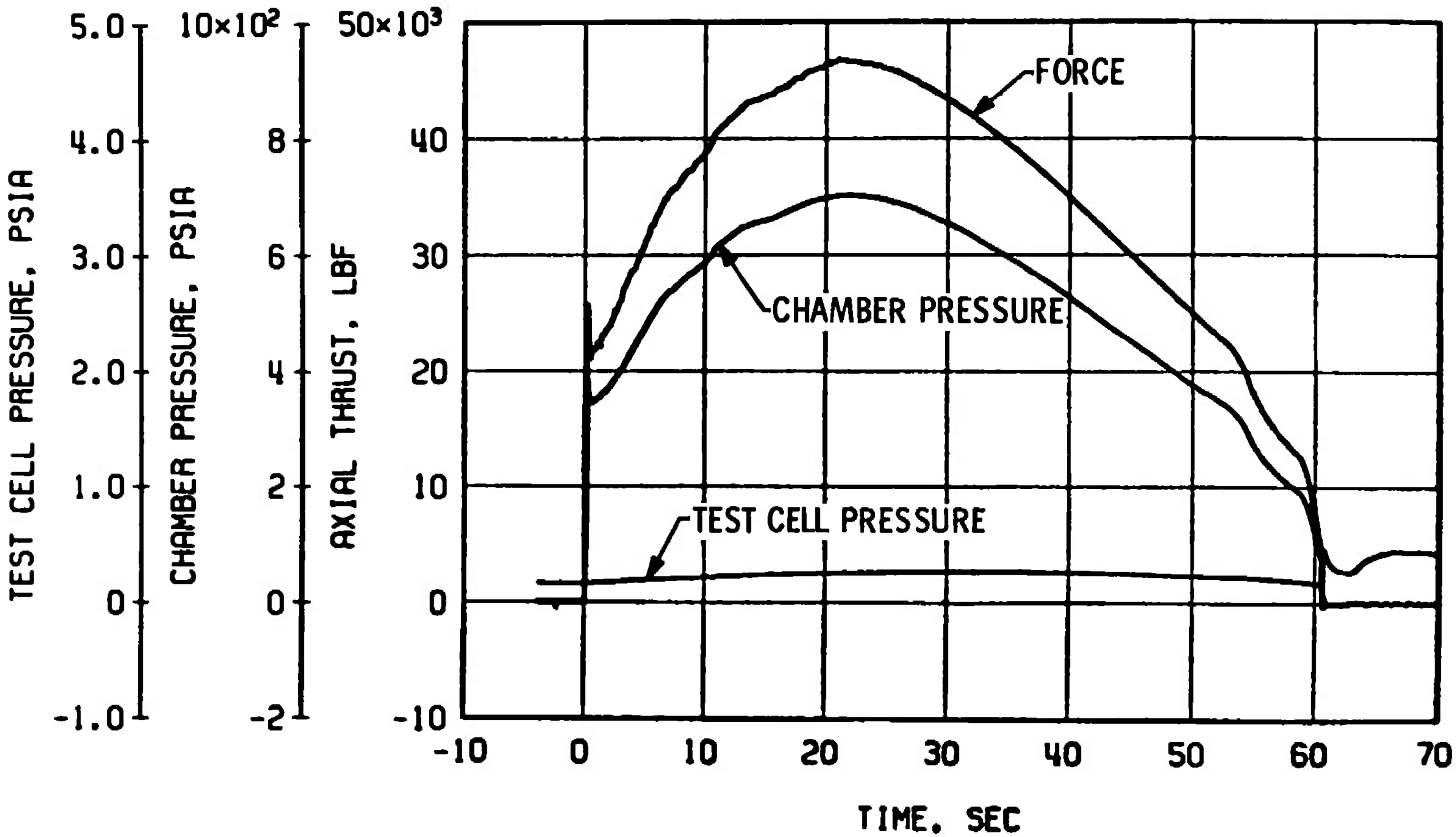


Fig. 4 Measured Axial Force, Chamber Pressure, and Test Cell Pressure during Motor Operation

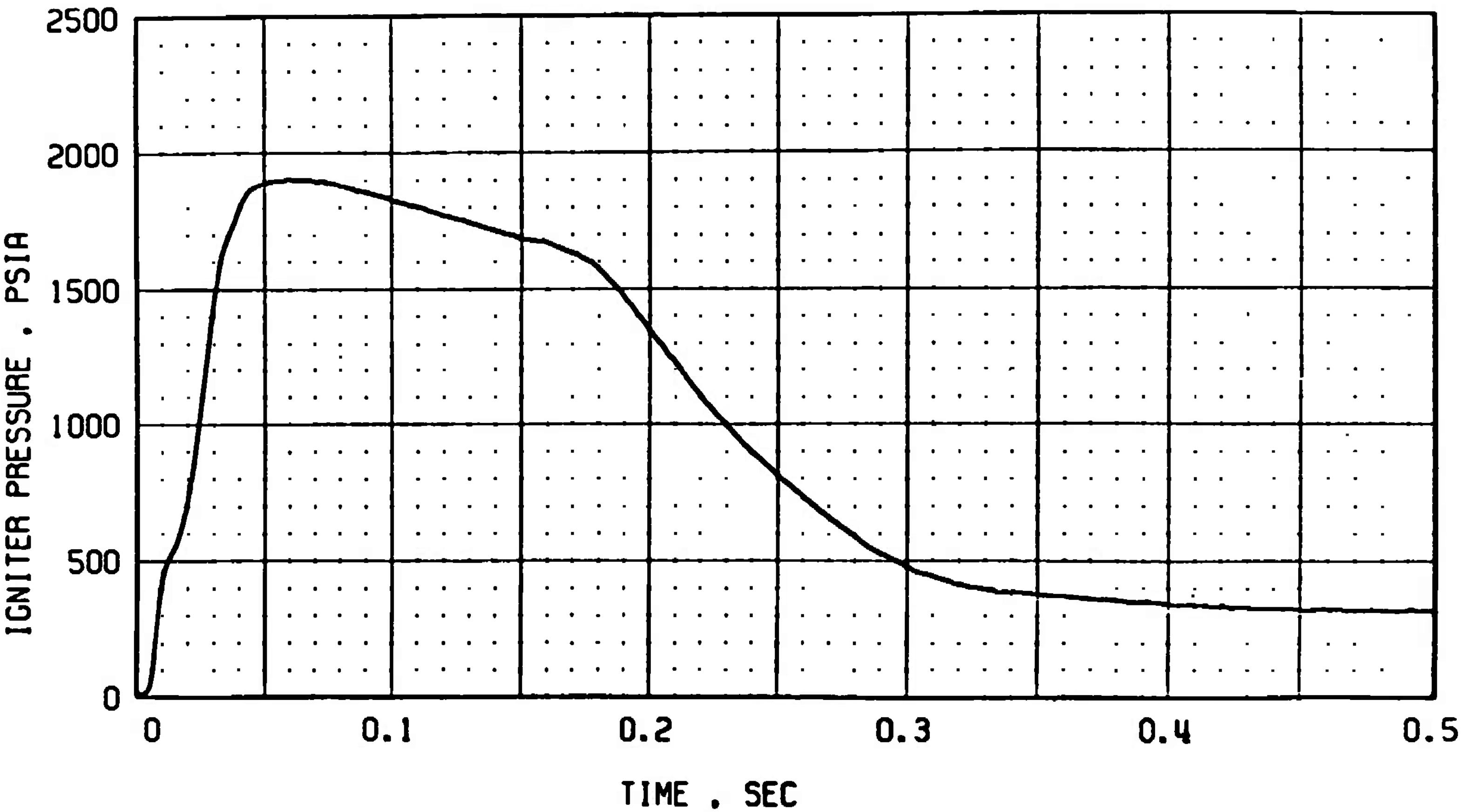


Fig. 5 Igniter Pressure Ignition Transient

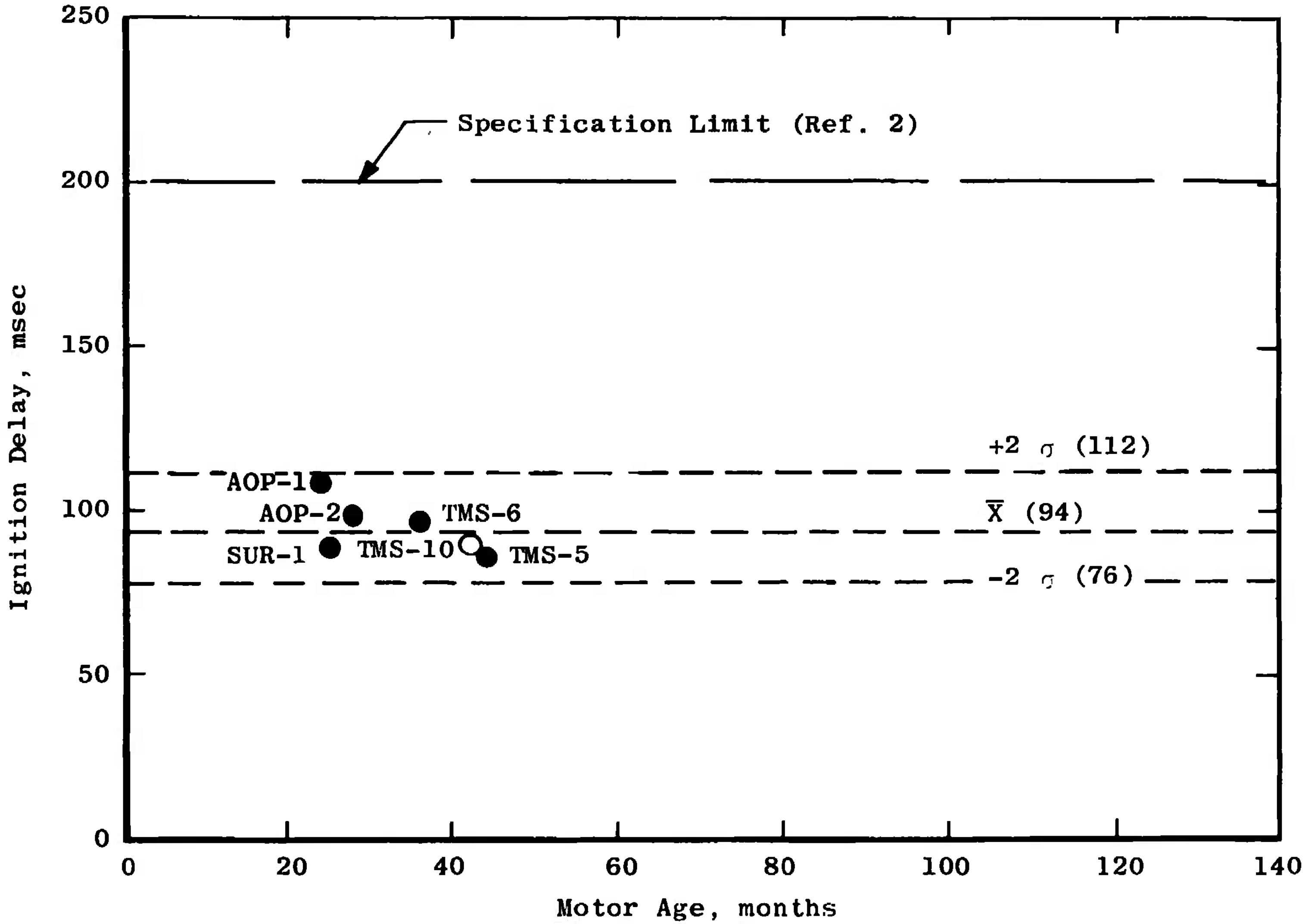


Fig. 6 Historical and Statistical Data for Ignition Delay for LGM-30G Stage III A&S Motors Fired at AEDC

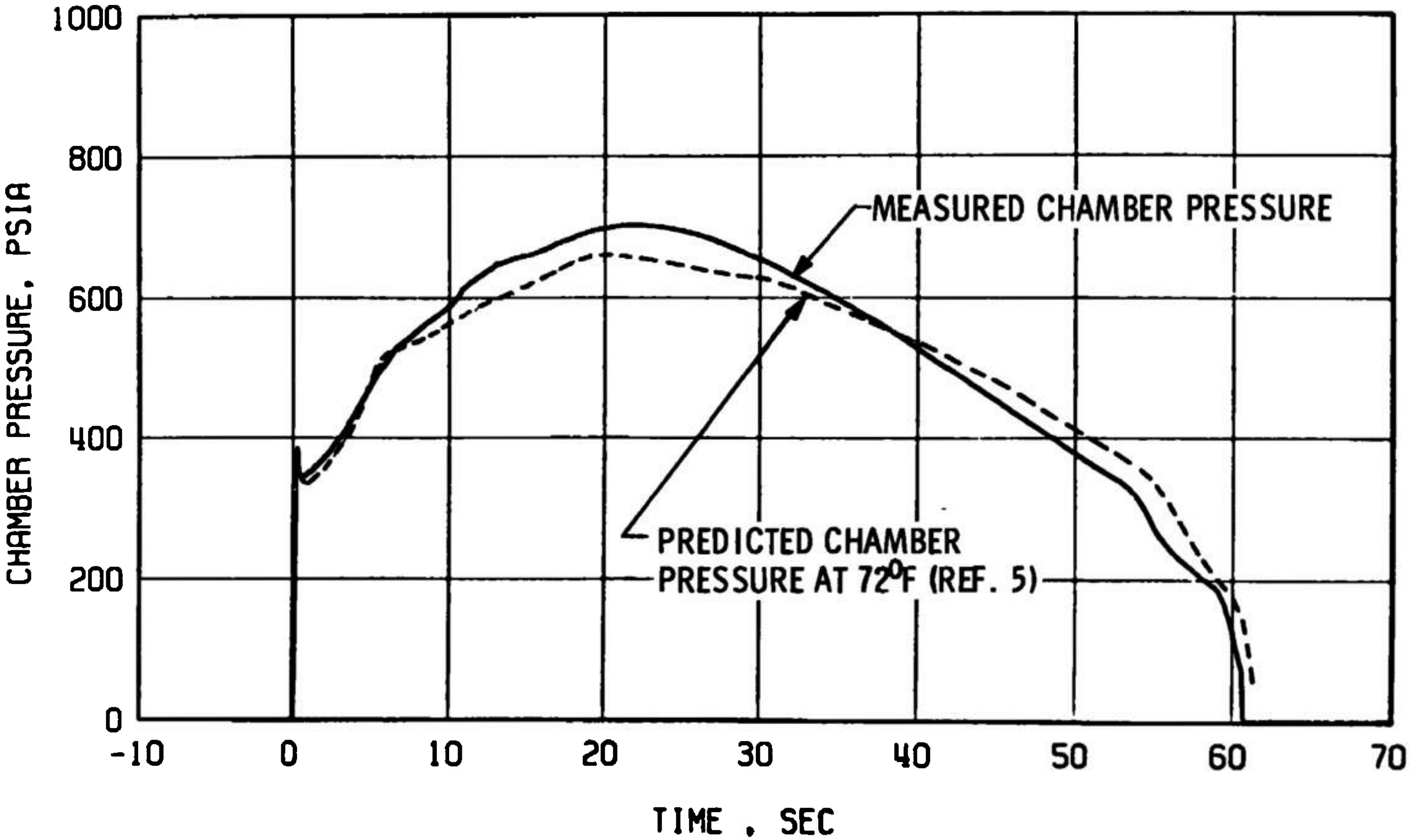


Fig. 7 Measured and Predicted Motor Chamber Pressure

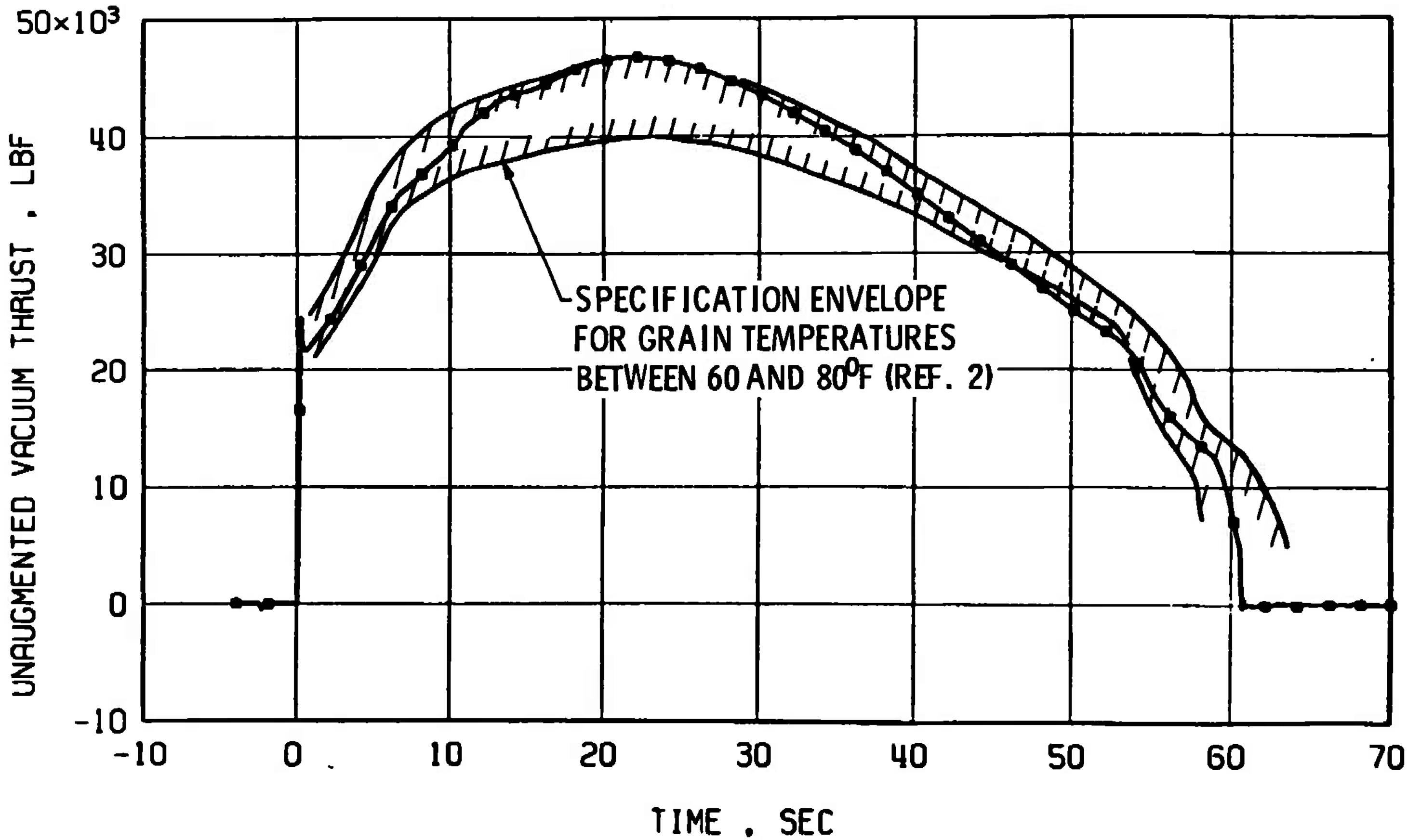


Fig. 8 Unaugmented Vacuum Thrust and Specification Envelope

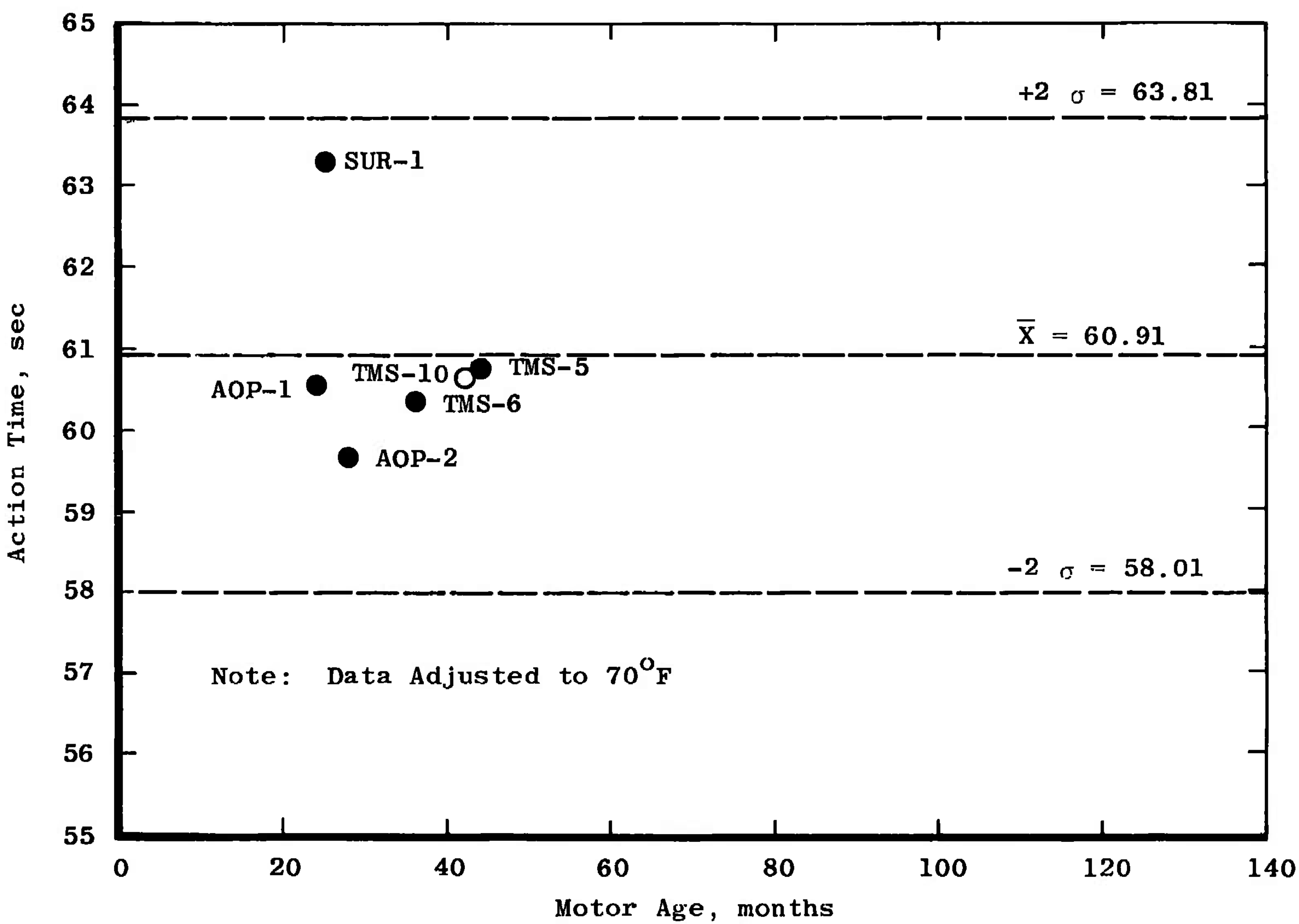


Fig. 9 Historical and Statistical Data for Action Time for LGM-30G Stage III A&S Motors Fired at AEDC

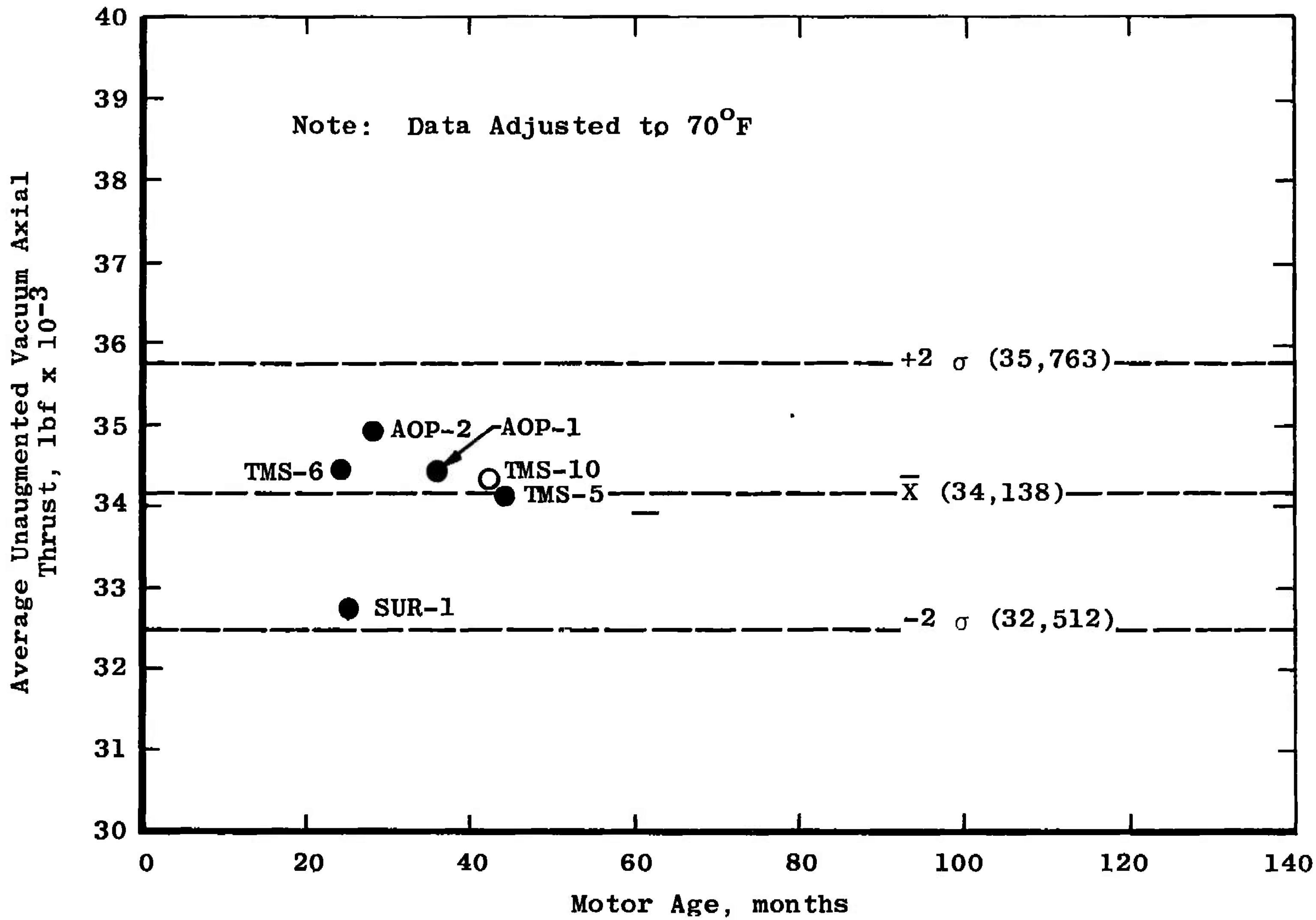


Fig. 10 Historical and Statistical Data for Average Unaugmented Vacuum Axial Thrust for LGM-30G Stage III A&S Motors Fired at AEDC

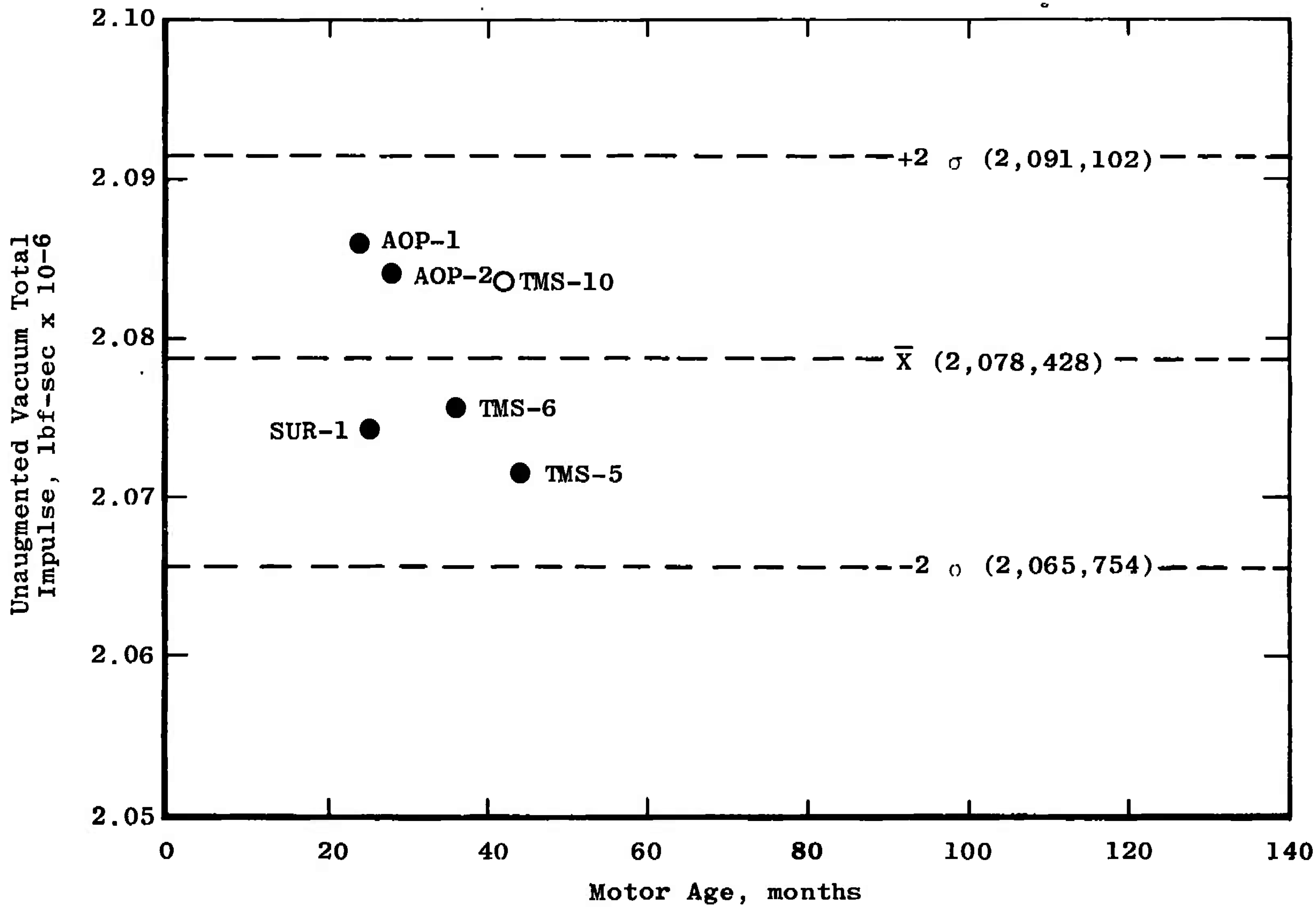


Fig. 11 Historical and Statistical Data for Unaugmented Vacuum Total Impulse for LGM-30G Stage III A&S Motors Fired at AEDC

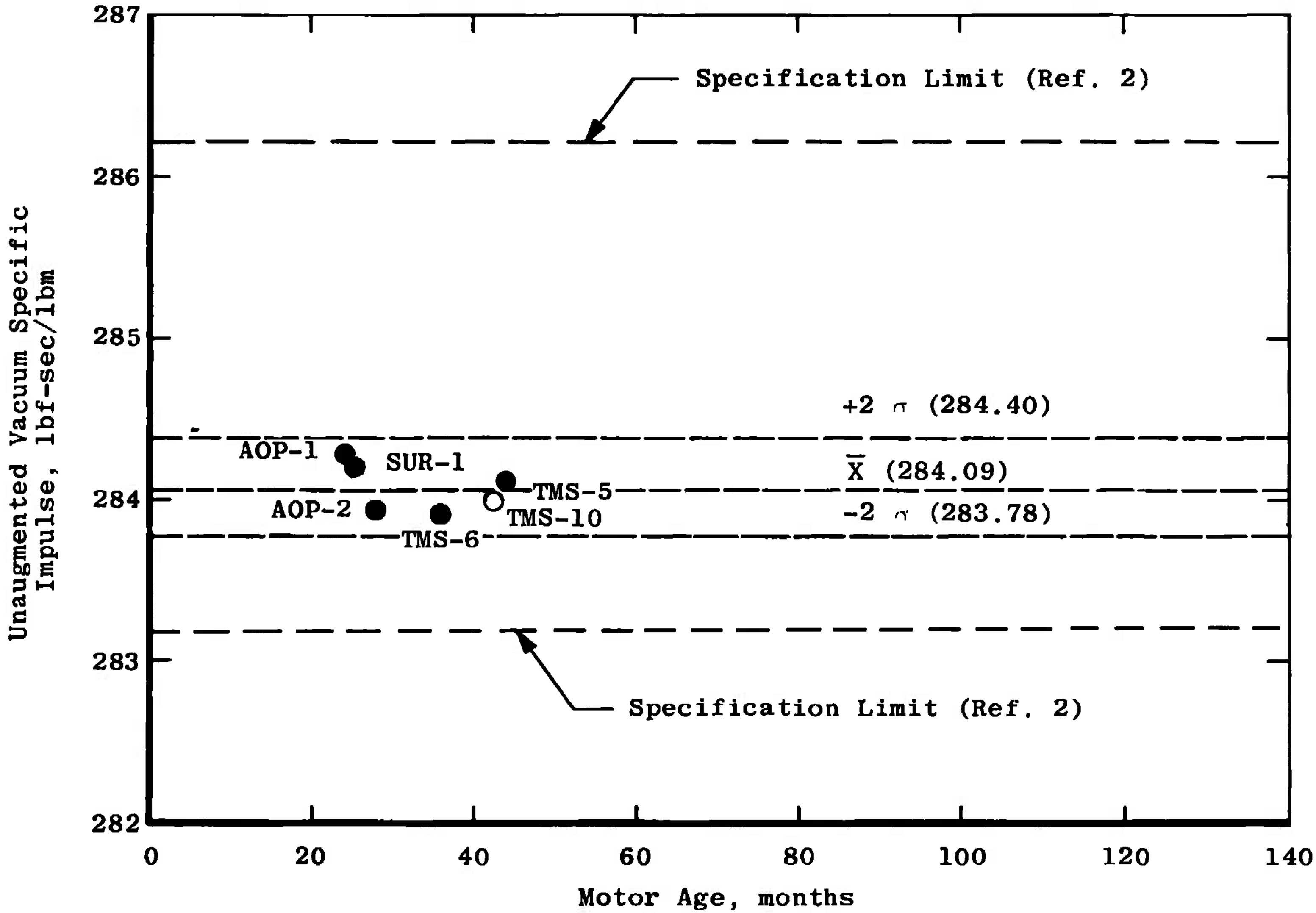


Fig. 12 Historical and Statistical Data for Unaugmented Vacuum Specific Impulse for LGM-30G Stage III A&S Motors Fired at AEDC

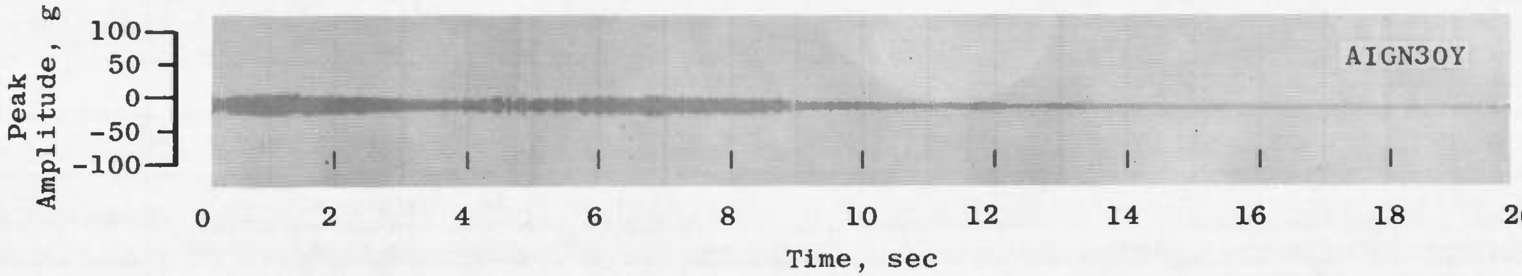


Fig. 13 Standard Motor Accelerometer Vibrations

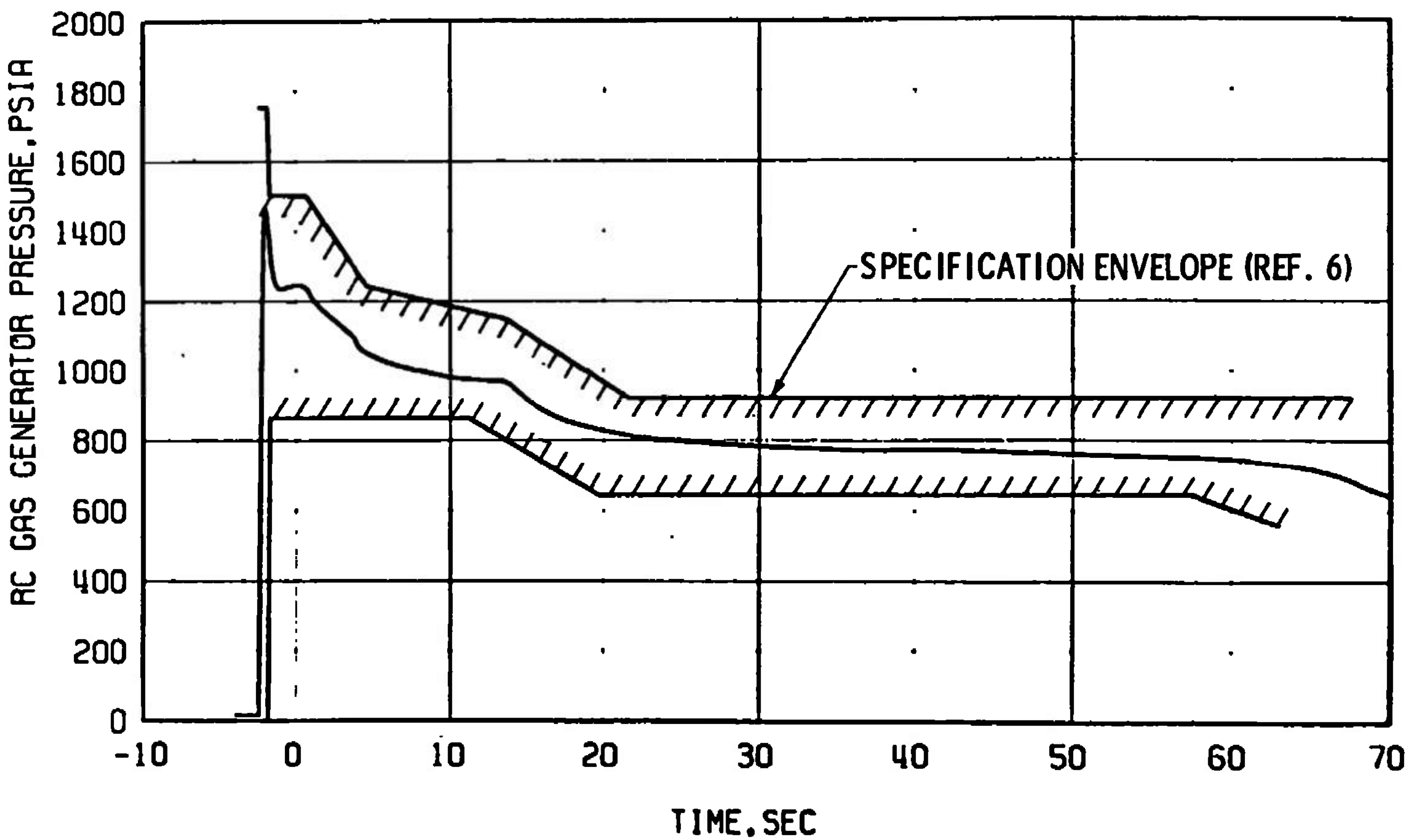
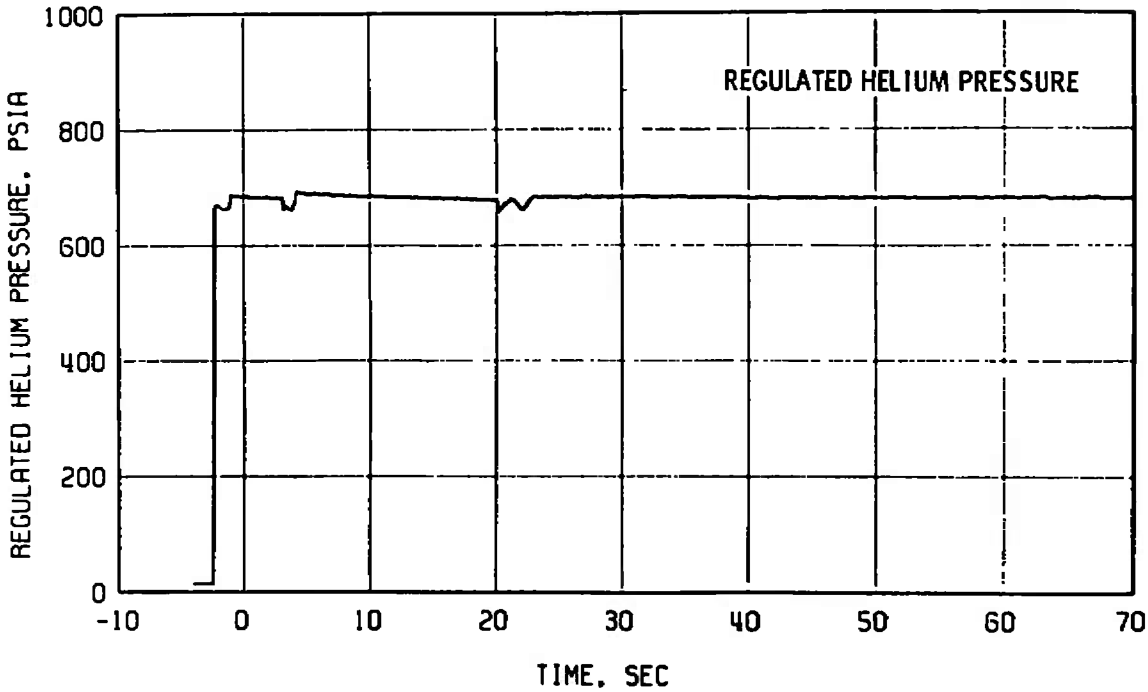


Fig. 14 Roll Control Gas Generator Pressure and Specification Envelope



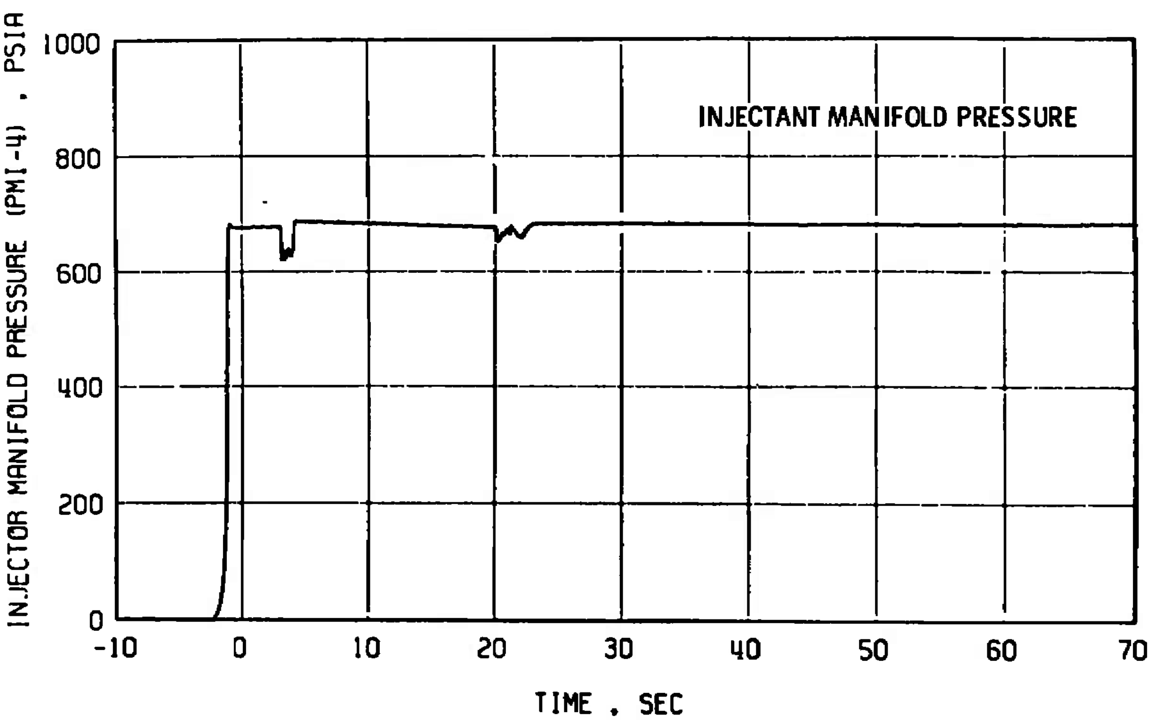
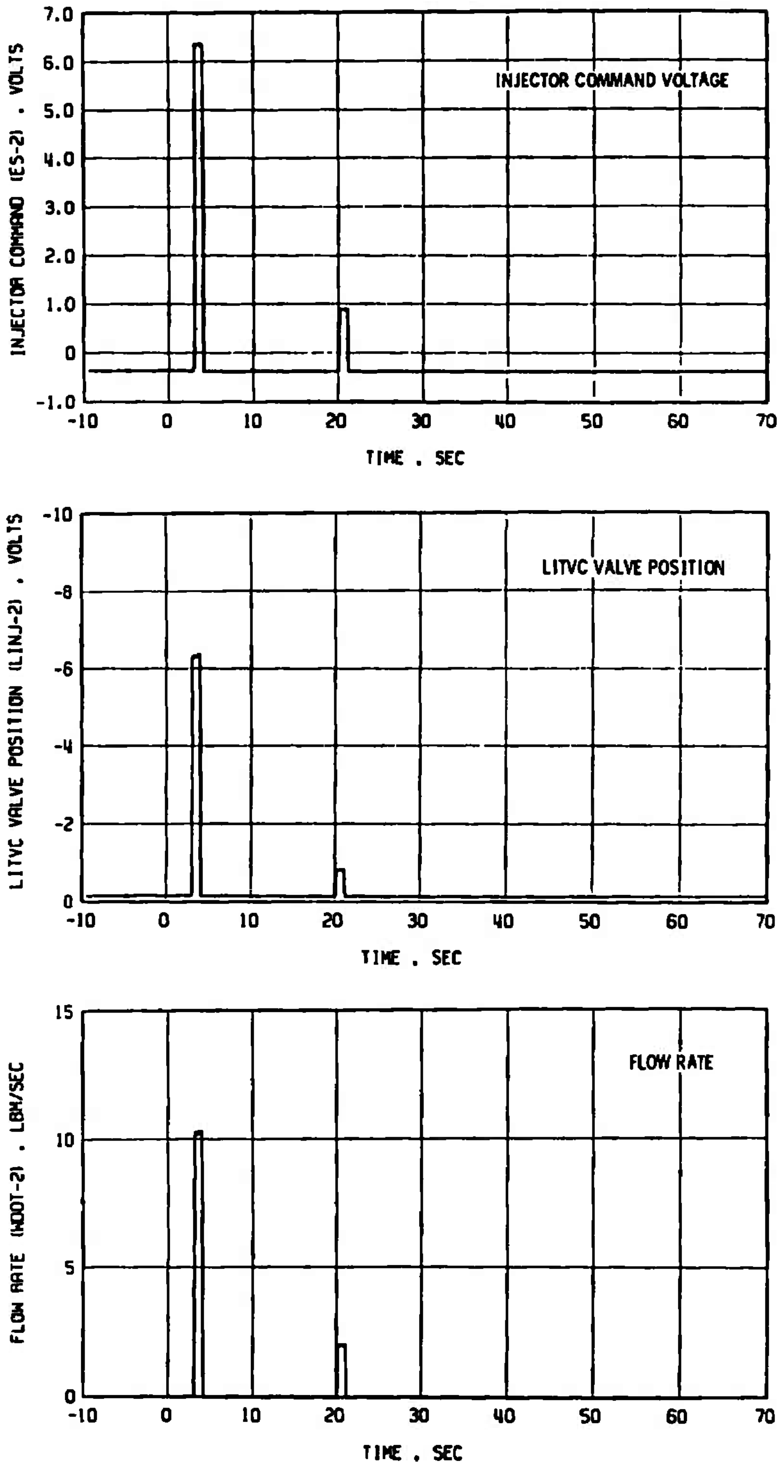
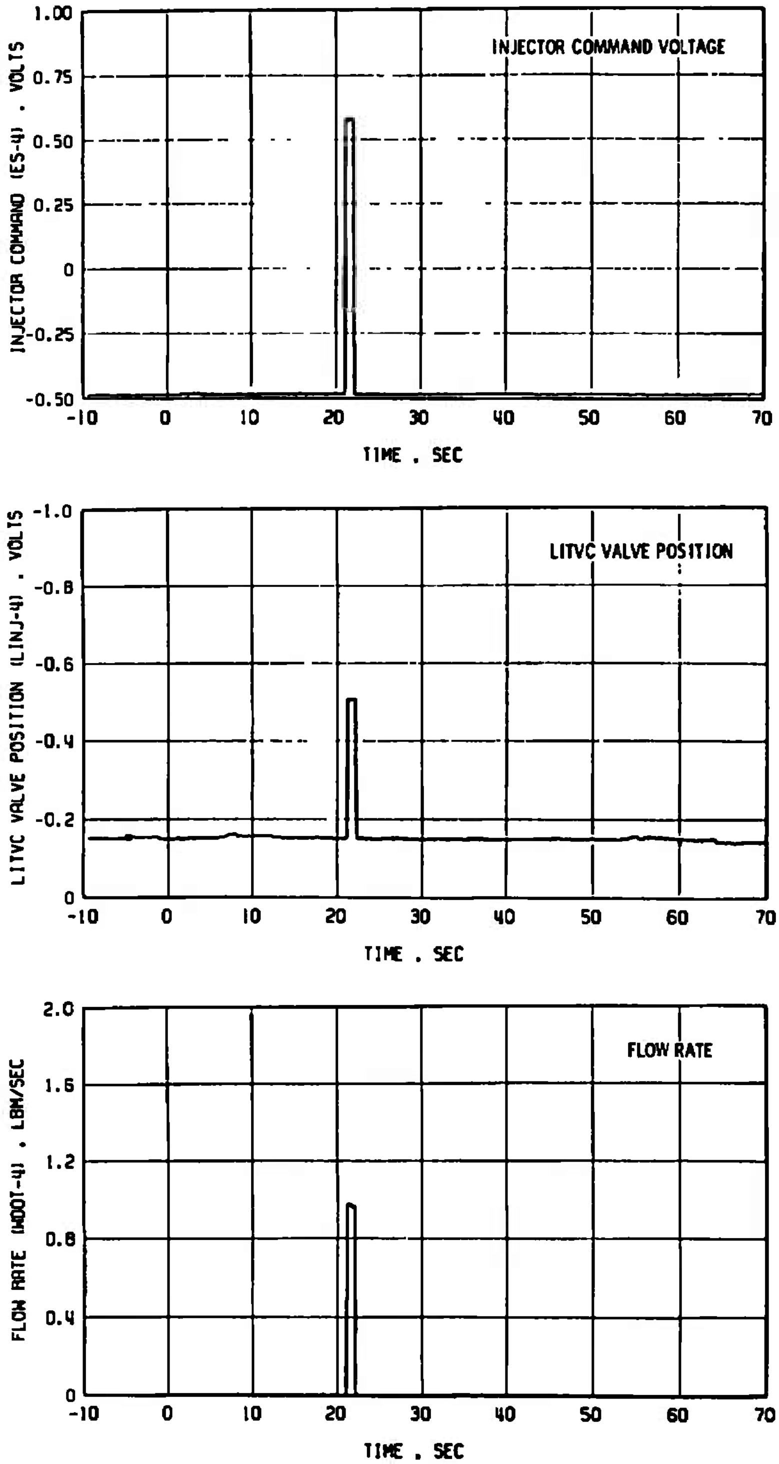


Fig. 15 Regulated Helium and Injectant Manifold Pressures during Motor Operation



a. Valve 2

Fig. 16 Thrust Vector Control Data Summary



b. Valve 4
Fig. 16 Concluded

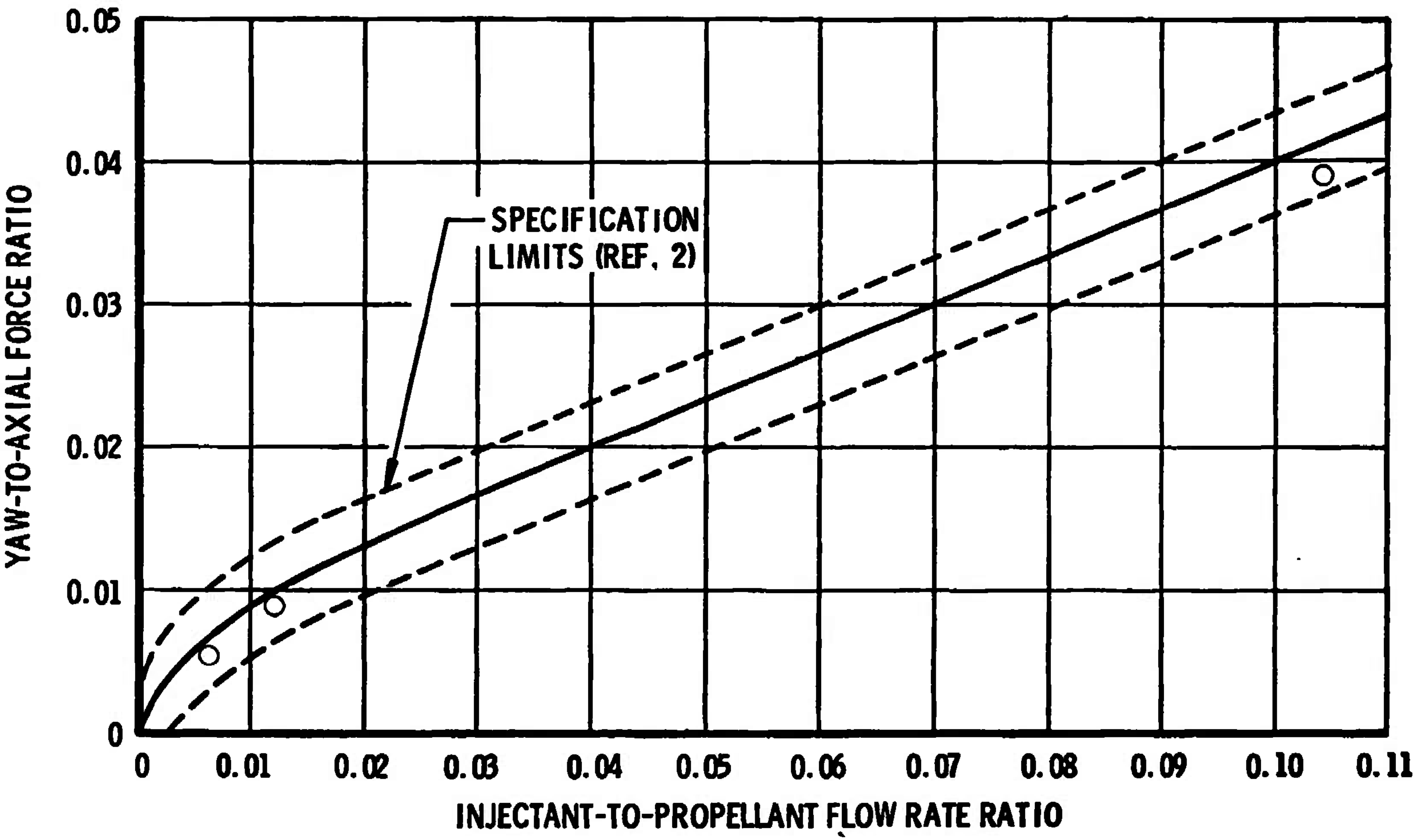
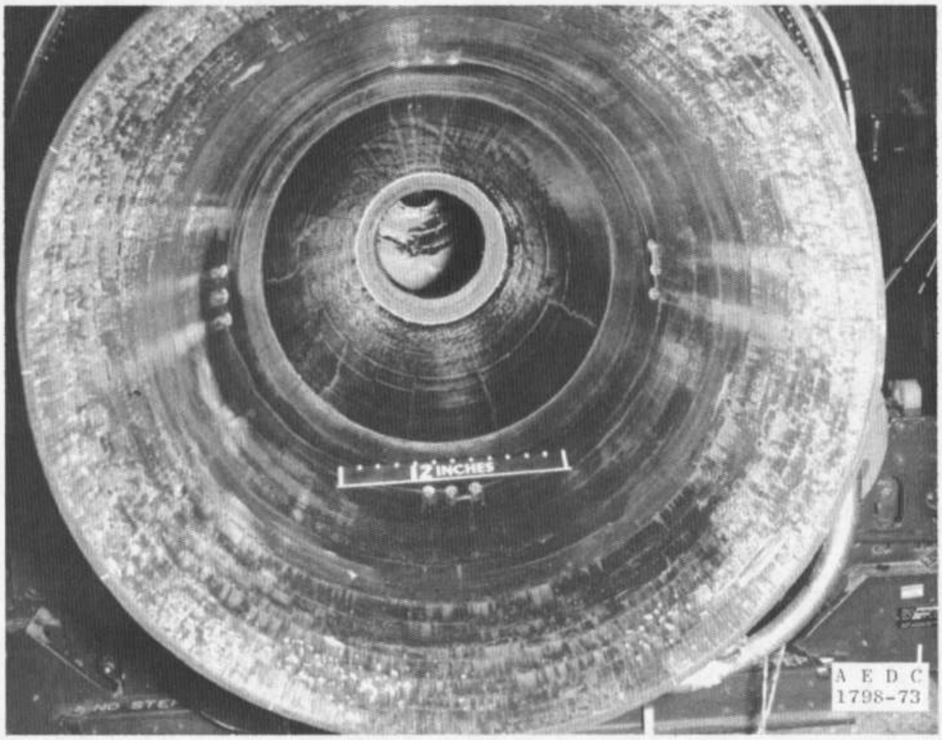
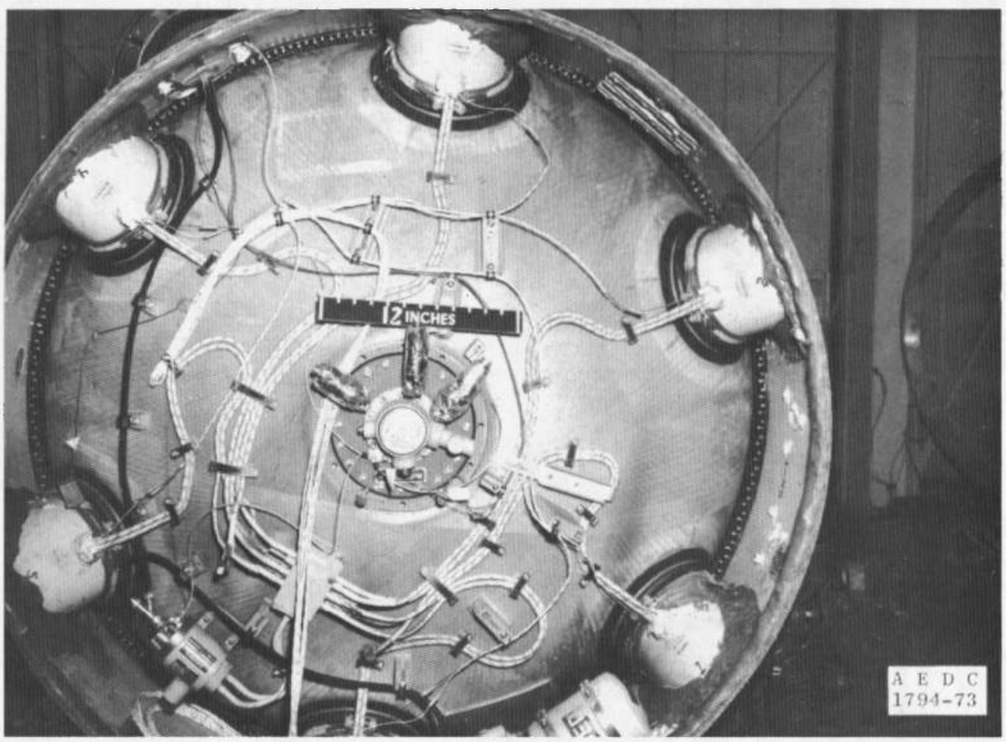


Fig. 17 Liquid-Injection Thrust Vector Control System Gain and Specification



a. Nozzle Exit



b. Forward Dome
Fig. 18 Motor Postfire Condition

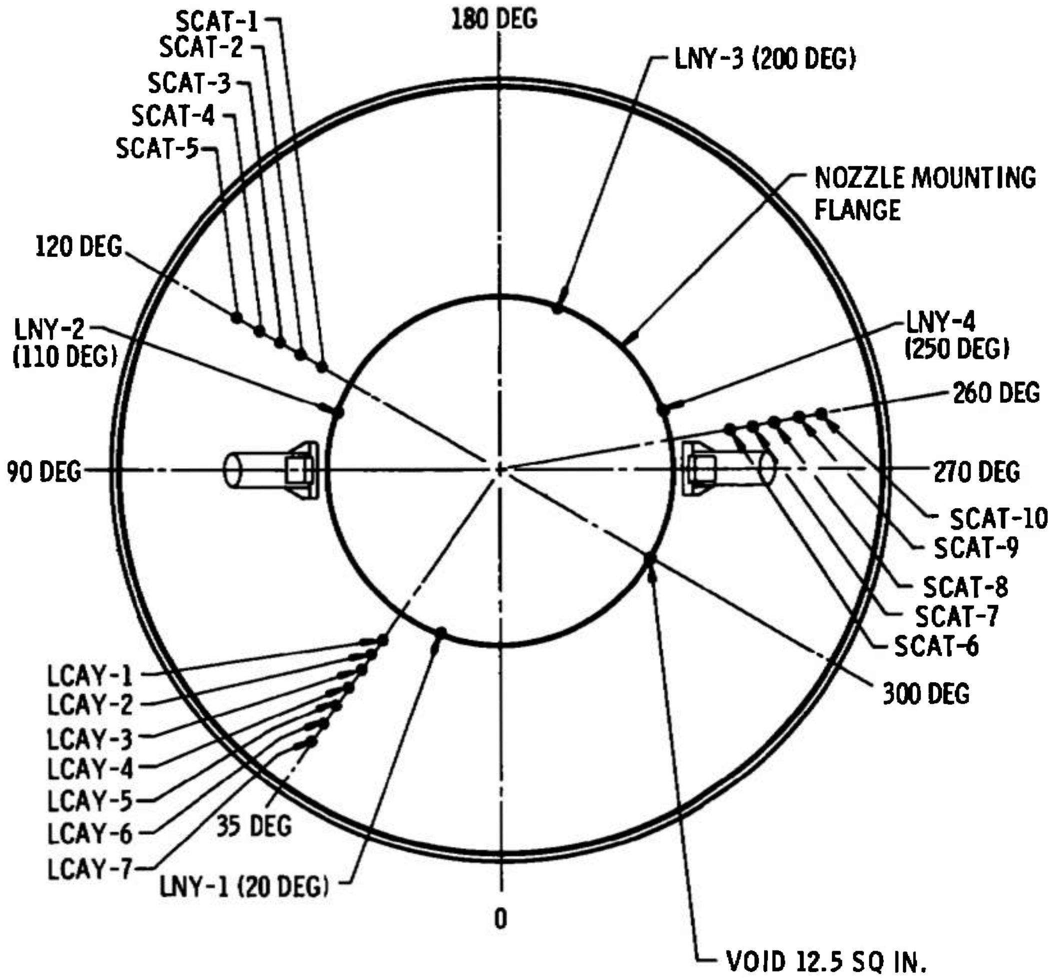


Fig. 19 Aft Dome Displacement Instrumentation Location Schematic

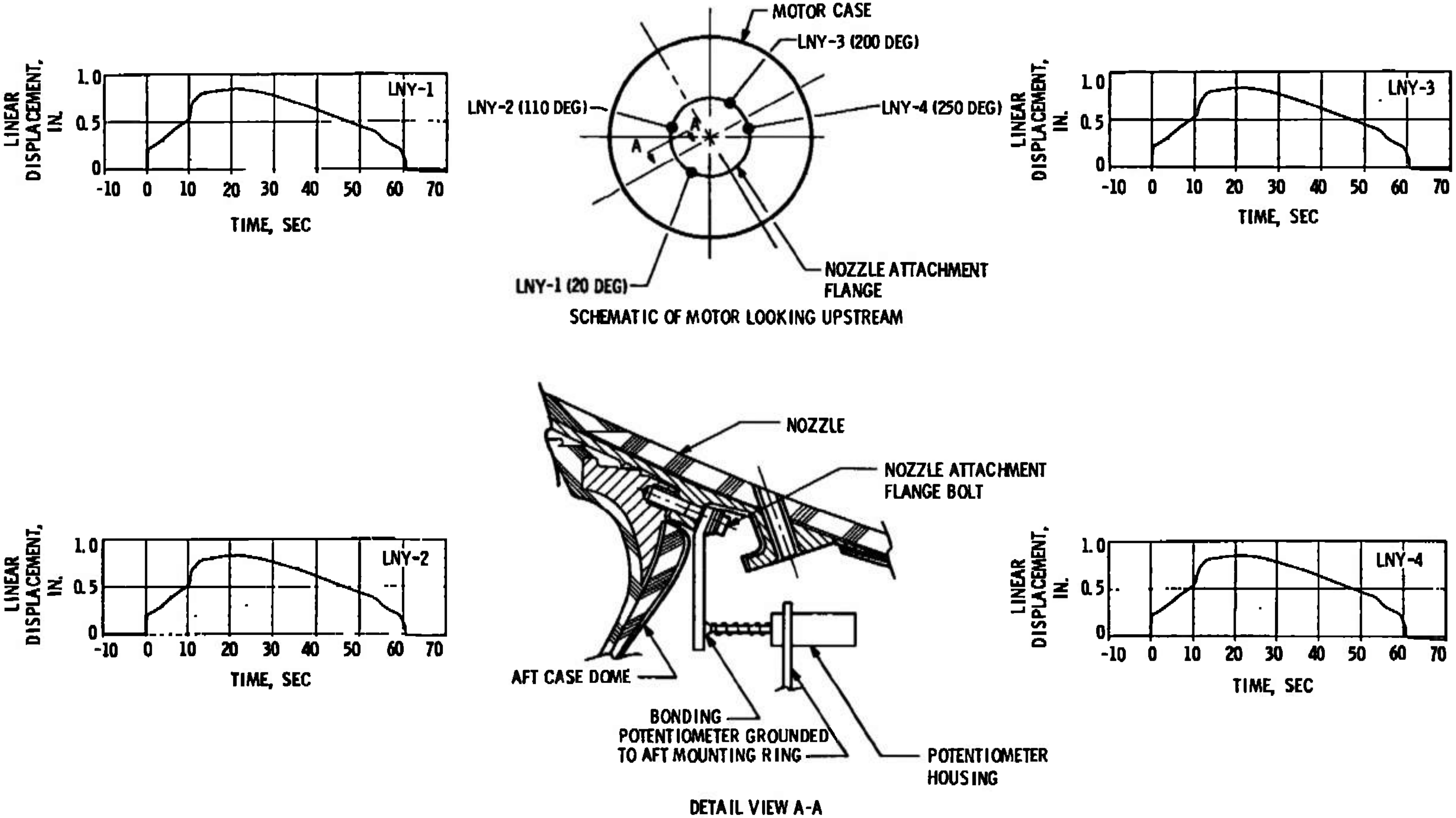


Fig. 20 Nozzle Mounting Flange Displacement History

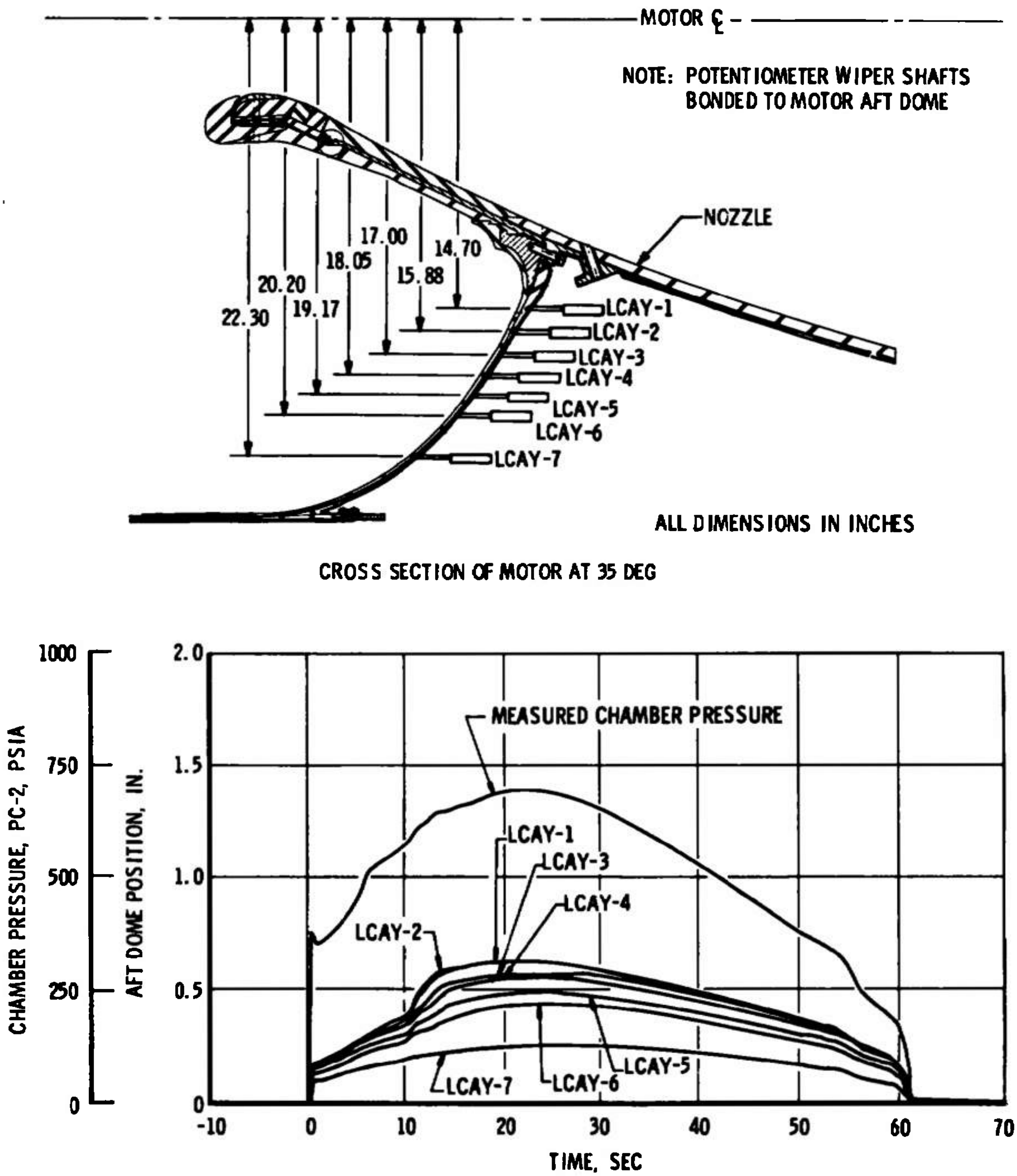
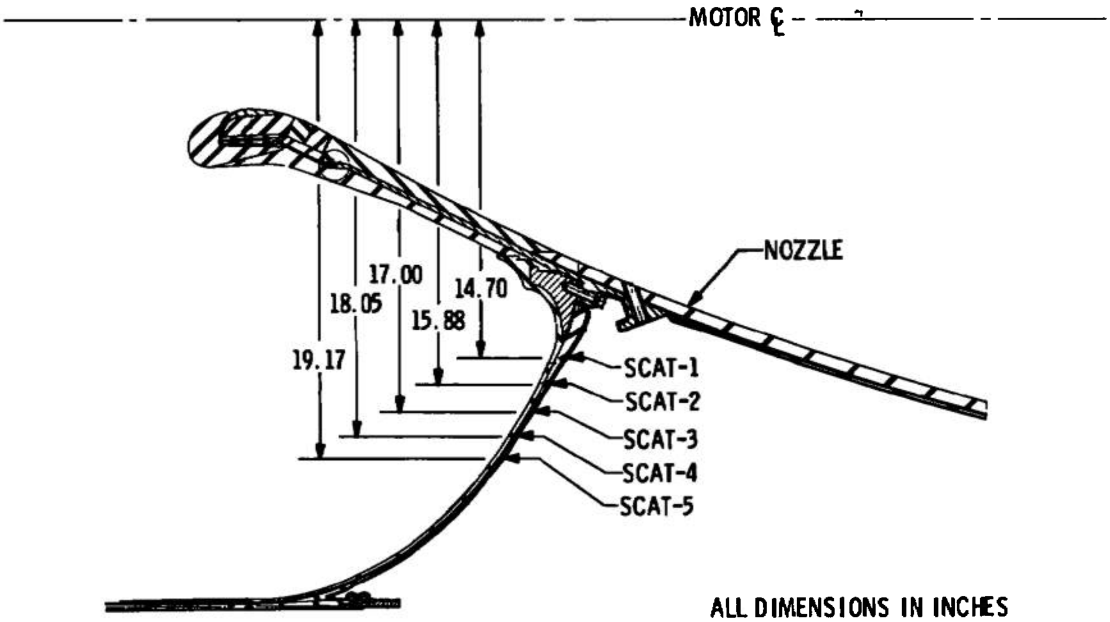
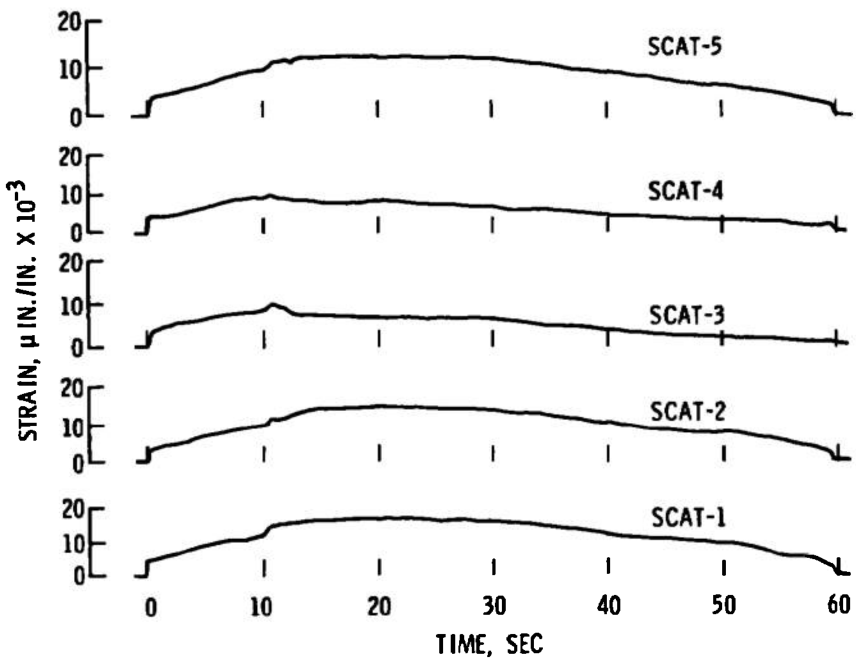


Fig. 21 Nozzle Case Aft Dome Growth History



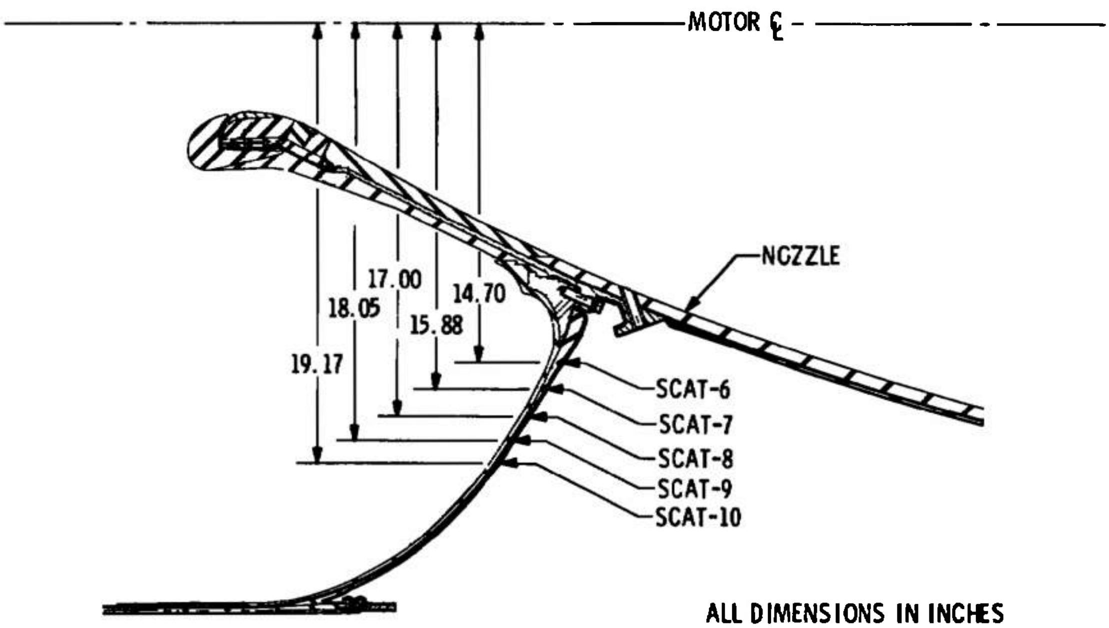
CROSS SECTION OF MOTOR AT 120 DEG

I. STRAIN-GAGE LOCATION



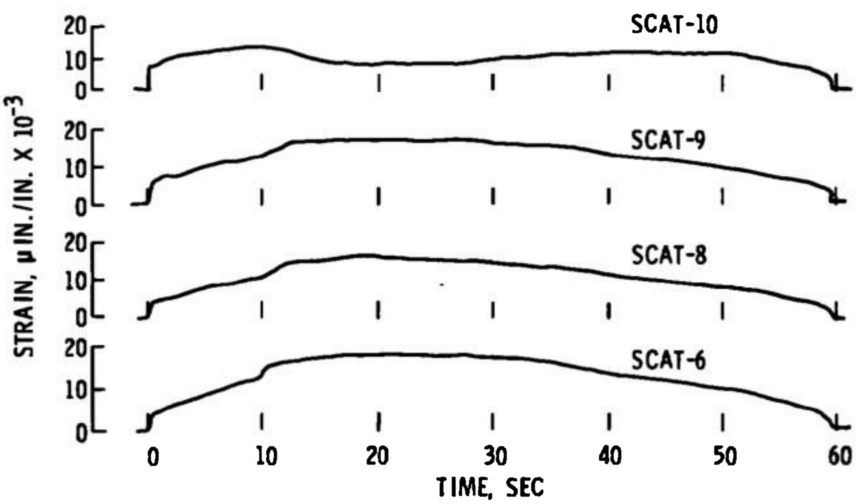
II. STRAIN HISTORY

a. Strain History at 120-deg Cross Section
Fig. 22 Histories of Aft Dome Strain-Gage Data



CROSS SECTION OF MOTOR AT 260 DEG

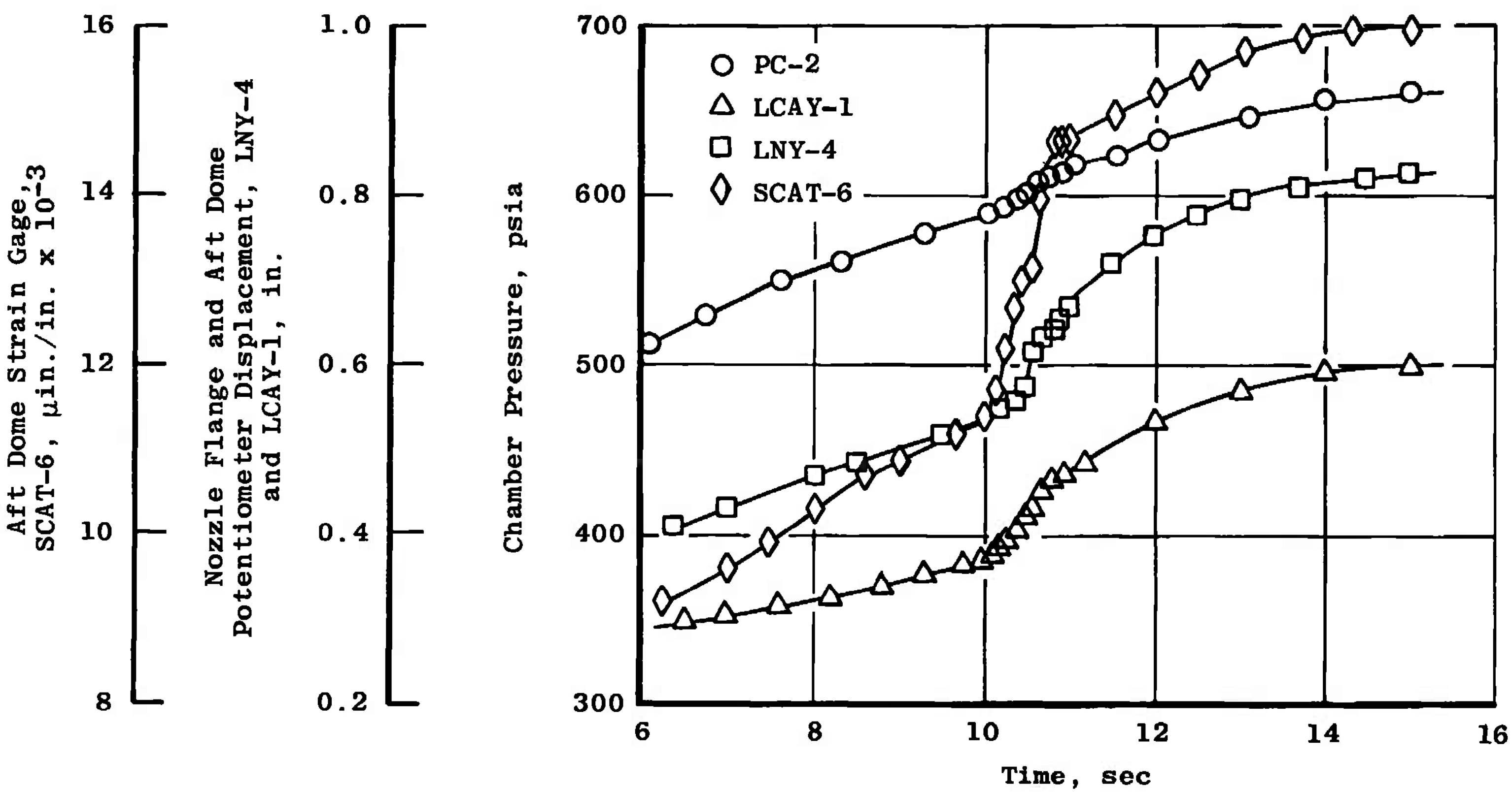
I. STRAIN-GAGE LOCATION



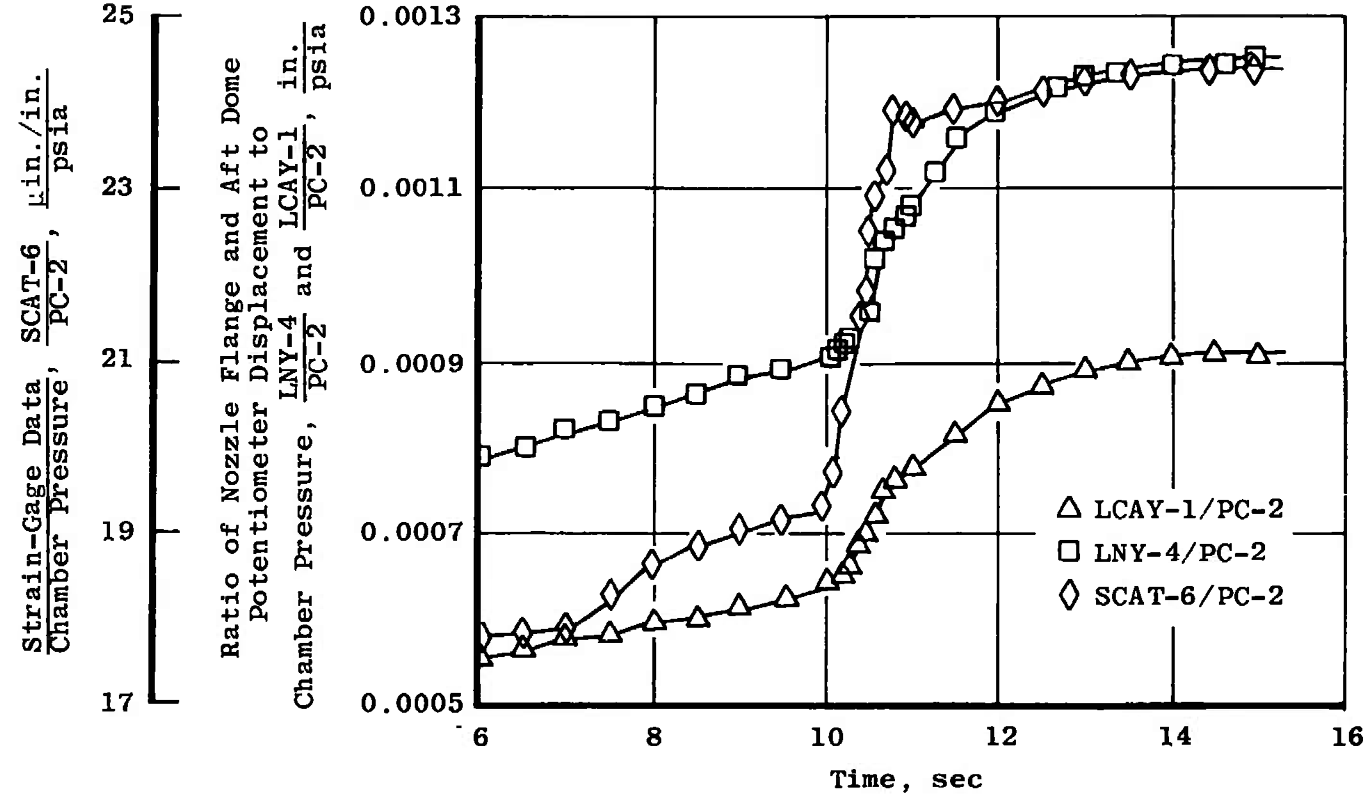
II. STRAIN HISTORY

b. Strain History at 260-deg Cross Section

Fig. 22 Concluded



a. Selected Potentiometer and Strain-Gage Data
Fig. 23 Partial Histories at Time of Indicated Aft Dome Displacement



b. Selected Potentiometer and Strain-Gage Data Ratioed to Chamber Pressure
Fig. 23 Concluded

TABLE I
TEST ARTICLE CONFIGURATION

Nomenclature	Part No.	Serial No.
Motor Assembly	1145623-239K	0000215
Propellant	ANB-3066	M5005 & M3502
Nozzle, Exhaust	1146002-39C	0000069
Housing, Nozzle	1144447-19B	D50537
Extension, Exit Cone	1145027-1C	SWU 131
Exit Cone	1127578-1E	SWU 145
Igniter and S&A Assembly	1128361-1296	0000239
Igniter Rocket Motor	1128360-79E	0000239
Safe and Arm	KR80000-09N	24842
Chamber	1143932-49G	0000215
Thrust Termination System	1128778-89K	N/A
Ring Assy, Retaining	1215685-15M	1429 1445 1432 1447 1440 1181
Block Assy, Manifold	1214311-21J	0000191
Ordnance Subsystem	1144463-49E	TX-056
A/D S&A Mechanism	1214110-7K	0000046
Igniter Assy, (Roll Control)	20565-H	P-0209
Roll Control Assy	1128070-9M	P-0000067
Valve Assy	101-58004A	118
Gas Generator Assy	20840-1A	P-0190
LITVC System	1145433-109G	N/A
Injectant Tank Assy	1145560-59G	0000098
Helium Tank Assy	1128811-109K	0000090
Pressurization Package	1128115-27F	0000100
Pressure Switch	1128084-7E	0000311
Manifold Assy	1145522-19C	43
Servoinjector Valves*		
0°	401-09140-10M	HCC004
90°	401-09140-10	HSD0131
180°	401-09140-03M	HCC0006
270°	401-09140-10	HSD0099
Operational Pressure Transducers		
PC-1	1143914-1A	40
PMI-4	1143914-3A	158
PRCGG	1143914-5A	206

*Valves cleaned and checked at AEDC for use on subsequent LGM-30G Stage III motors.

TABLE II
INSTRUMENTATION SUMMARY

PARAMETER SYMBOL	PARAMETER DESCRIPTION	MEASUREMENT RANGE	SENSOR TYPE	SENSOR RANGE	DIGITAL* SYSTEM	ANALOG TAPE	OSCILLOGRAPH	STRIP CHART
	ACCELERATION	G PEAK		G PEAK				
AFS-262Y	FORWARD SKIRT @ 262	-100 TO 100	PIEZOELECTRIC	1K TO 1K		X		
AIGN30Y	IGNITER BOSS @ 30	-100 TO 100	PIEZOELECTRIC	1K TO 1K		X		
AIGN330Y	IGNITER BOSS @ 330	-100 TO 100	PIEZOELECTRIC	1K TO 1K		X		
	EVENT-VOLTAGE	V DC						
EFS-1	MAIN MOTOR IGNITION	0 TO 28			X**	X	X	
EFS-2	MAIN MOTOR IGNITION	0 TO 28			X**		X	
EFS-3	LITVC IGNITION	0 TO 28			X		X	
EFS-4	LITVC IGNITION	0 TO 28			X		X	
EFS-5	ROLL CONTROL IGNIT.	0 TO 28			X		X	
EFS-6	ROLL CONTROL IGNIT.	0 TO 28			X		X	
EFS-9	AOTT IGNITION	0 TO 4.4			X	X	X	
EFS-10	AOTT IGNITION	0 TO 28			X		X	
	EVENT	VOLTS						
EISA	IGNITER S/A ARMING	0 TO 40			X		X	
EQA	AFT NOZZLE QUENCH	0 TO 10			X		X	
EQF	FORWARD TT QUENCH	0 TO 10			X		X	
ERCV-1	RC COMMAND VOLTAGE	- 30 TO 30			X**		X	
ERDB	RUPTURE DISC BREAKWR	0 TO 1000			X			
ES-2	INJ VALVE #2 COMMAND	0 TO 10			X		X	
ES-4	INJ VALVE #4 COMMAND	0 TO 10			X		X	
ETSTT-1	TT PORT #1	0 TO 1000			X	X		
ETSTT-2	TT PORT #2	0 TO 1000			X	X		
ETSTT-3	TT PORT #3	0 TO 1000			X	X		
ETSTT-4	TT PORT #4	0 TO 1000			X	X		
ETSTT-5	TT PORT #5	0 TO 1000			X	X		
ETSTT-6	TT PORT #6	0 TO 1000			X	X		
ETTPS	LAUNCH LIMIT SWITCH	0 TO 10			X		X	
	FORCE	LBF		LBF				
FXAL-1	AFT PITCH LEFT	-5000 TO 5000	STRAIN GAGE	6K TO 6K	X		X	
FXAL-2	AFT PITCH LEFT	-5000 TO 5000	STRAIN GAGE	6K TO 6K		X		
FXAR-1	AFT PITCH RIGHT	-5000 TO 5000	STRAIN GAGE	6K TO 6K	X		X	
FXAR-2	AFT PITCH RIGHT	-5000 TO 5000	STRAIN GAGE	6K TO 6K		X		
FXF-1	FORWARD PITCH	-5000 TO 5000	STRAIN GAGE	6K TO 6K	X		X	

TABLE II (Continued)

PARAMETER SYMBOL	PARAMETER DESCRIPTION	MEASUREMENT RANGE	SENSOR TYPE	SENSOR RANGE	DIGITAL* SYSTEM	ANALOG TAPE	OSCILLO-GRAPH	STRIP CHART
	PRESSURE	PSIA		PSIA				
PA-1	TEST CELL	0 TO 1	STRAIN GAGE	0 TO 1	X		X	X
PA-2	TEST CELL	0 TO 1	STRAIN GAGE	0 TO 1	X			
PA-5	TEST CELL	0 TO 15	STRAIN GAGE	0 TO 15	X			
PC-1	MOTOR CHAMBER	0 TO 750	STRAIN GAGE	0 TO 750	X	X	X	
PC-1F	MOTOR CHAMBER (FILT)	- 25 TO 25	STRAIN GAGE	0 TO 750		X		
PC-2	MOTOR CHAMBER	0 TO 750	STRAIN GAGE	0 TO 1000	X**	X	X	X
PFDA-1	FORWARD DOME AREA	0 TO 10	STRAIN GAGE	0 TO 10	X		X	X
PFDA-2	FORWARD DOME AREA	0 TO 25	STRAIN GAGE	0 TO 25	X	X		
PDF	GN2 DIF ORIFICE	-100 TO 100	STRAIN GAGE	-100 TO 100	X			
PI-1	IGNITER	0 TO 3000	STRAIN GAGE	0 TO 3000	X**	X	X	
PINJ-1	INJECTOR VALVE #1	0 TO 1000	STRAIN GAGE	0 TO 1000	X		X	
PINJ-3	INJECTOR VALVE #3	0 TO 1000	STRAIN GAGE	0 TO 1000	X		X	
PMI-4	MANIFOLD INJECTANT	0 TO 1000	STRAIN GAGE	0 TO 1000	X		X	
PNS	GN2 SUPPLY	0 TO 500	STRAIN GAGE	0 TO 500	X			
PQA	AFT NOZZLE QUENCH	0 TO 200	STRAIN GAGE	0 TO 200	X			
PQF	FORWARD TT QUENCH	0 TO 200	STRAIN GAGE	0 TO 200	X			
PRCGG	ROLL CONTROL GAS GEN	0 TO 1500	STRAIN GAGE	0 TO 1500	X		X	
PREG	REGULATED HELIUM	0 TO 1000	STRAIN GAGE	0 TO 1000	X		X	X
PUNREG	UNREGULATED HELIUM	0 TO 4000	STRAIN GAGE	0 TO 5000	X		X	
	STRAIN	U IN/IN		U IN/IN				
SCAT-1	AFT DOME @ 100 DEG	1600 TO 16000	STRAIN GAGE	1600 TO 16000	X	X		
SCAT-2	AFT DOME @ 100 DEG	1600 TO 16000	STRAIN GAGE	1600 TO 16000	X	X		
SCAT-3	AFT DOME @ 100 DEG	1600 TO 16000	STRAIN GAGE	1600 TO 16000	X	X		
SCAT-4	AFT DOME @ 100 DEG	1600 TO 16000	STRAIN GAGE	1600 TO 16000	X	X		
SCAT-5	AFT DOME @ 100 DEG	1600 TO 16000	STRAIN GAGE	1600 TO 16000	X	X		
SCAT-6	AFT DOME @ 280 DEG	1600 TO 16000	STRAIN GAGE	1600 TO 16000	X	X		
SCAT-7	AFT DOME @ 280 DEG	1600 TO 16000	STRAIN GAGE	1600 TO 16000	X	X		
SCAT-8	AFT DOME @ 280 DEG	1600 TO 16000	STRAIN GAGE	1600 TO 16000	X	X		
SCAT-9	AFT DOME @ 280 DEG	1600 TO 16000	STRAIN GAGE	1600 TO 16000	X	X		
SCAT-10	AFT DOME @ 280 DEG	1600 TO 16000	STRAIN GAGE	1600 TO 16000	X	X		
SHT-1	HELIUM TANK	5000 TO 5000	STRAIN GAGE	5000 TO -5000	X	X		
SHT-2	HELIUM TANK	5000 TO 5000	STRAIN GAGE	5000 TO -5000	X	X		
	TEMPERATURE	DEG. F		DEG. F				
TA-1	AMBIENT TEST CELL	0 TO 100	C/A, TYPE K	-300 TO 2500				X
TA-2	AMBIENT TEST CELL	0 TO 500	C/A, TYPE K	-300 TO 2500	X			
TA-5	AMBIENT CELL	0 TO 200	C/A, TYPE K	-300 TO 2500	X			
TF-1	FORWARD GN2 FLOW LN	0 TO 200	C/A, TYPE K	-300 TO 2500	X			
TP-1	PROPELLANT GRAIN	0 TO 100	C/A, TYPE K	-300 TO 2500				X
TP-2	PROPELLANT GRAIN	0 TO 350	C/A, TYPE K	-300 TO 2500	X			

TABLE II (Concluded)

PARAMETER SYMBOL	PARAMETER DESCRIPTION	MEASUREMENT RANGE	SENSOR TYPE	SENSOR RANGE	DIGITAL* SYSTEM	ANALOG TAPE	OSCILLO-GRAPH	STRIP CHART
	FORCE	LBF		LBF				
FXF-2	FORWARD PITCH	-5000 TO 5000	STRAIN GAGE	6K TO 6K		X		
FY-1	AXIAL THRUST	-10000 TO 50000	STRAIN GAGE	100K TO 100K	X		X	X
FY-2	AXIAL THRUST	-10000 TO 50000	STRAIN GAGE	100K TO 100K	X			
FY-3F	AXIAL THRUST (FILT)	-5000 TO 5000	STRAIN GAGE	-100 TO 100	X	X		
FY-5	AXIAL THRUST	-10000 TO 50000	STRAIN GAGE	100K TO 100K		X		
FZA-1	AFT YAW	-1600 TO 1600	STRAIN GAGE	6K TO 6K	X		X	
FZA-2	AFT YAW	-1600 TO 1600	STRAIN GAGE	6K TO 6K	X			
FZA-3	AFT YAW	-1600 TO 1600	STRAIN GAGE	6K TO 6K		X		
FZF-1	FORWARD YAW	-500 TO 500	STRAIN GAGE	6K TO 6K	X		X	
FZF-2	FORWARD YAW	-500 TO 500	STRAIN GAGE	6K TO 6K	X			
FZF-3	FORWARD YAW	-500 TO 500	STRAIN GAGE	6K TO 6K		X		
	EVENT-CURRENT	AMPS						
IFS-1	MAIN MOTOR IGNITION	0 TO 5			X	X	X	
IFS-2	MAIN MOTOR IGNITION	0 TO 5			X		X	
IFS-3	LITVC IGNITION	0 TO 5			X		X	
IFS-4	LITVC IGNITION	0 TO 5			X		X	
IFS-5	ROLL CONTROL IGNIT.	0 TO 5			X		X	
IFS-6	ROLL CONTROL IGNIT.	0 TO 5			X		X	
IFS-9	ADTT IGNITION	0 TO 25			X	X	X	
IFS-10	ADTT IGNITION	0 TO 25			X		X	
IRCV-1	RC VALVE #1 COMMAND	0 TO 1.5			X		X	
	DISPLACEMENT	INCH		INCH				
LCAY-1	AFT DOME, AXIAL	- 1 TO 1	POTENTIOMETRIC	0 TO 2.0	X			
LCAY-2	AFT DOME, AXIAL	- 1 TO 1	POTENTIOMETRIC	0 TO 2.0	X			
LCAY-3	AFT DOME, AXIAL	- 1 TO 1	POTENTIOMETRIC	0 TO 2.0	X			
LCAY-4	AFT DOME, AXIAL	- 1 TO 1	POTENTIOMETRIC	0 TO 2.0	X			
LCAY-5	AFT DOME, AXIAL	- 1 TO 1	POTENTIOMETRIC	0 TO 2.0	X			
LCAY-6	AFT DOME, AXIAL	- 1 TO 1	POTENTIOMETRIC	0 TO 2.0	X			
LCAY-7	AFT DOME, AXIAL	- 1 TO 1	POTENTIOMETRIC	0 TO 2.0	X			
LNY-1	NOZZLE FLANGE, AXIAL	- 1 TO 1	POTENTIOMETRIC	0 TO 2.0	X			
LNY-2	NOZZLE FLANGE, AXIAL	- 1 TO 1	POTENTIOMETRIC	0 TO 2.0	X			
LNY-3	NOZZLE FLANGE, AXIAL	- 1 TO 1	POTENTIOMETRIC	0 TO 2.0	X			
LNY-4	NOZZLE FLANGE, AXIAL	- 1 TO 1	POTENTIOMETRIC	0 TO 2.0	X			
	POSITION	V DC		V DC				
LINJ-2	PINTLE VALVE #2	- 10 TO 0	LVDT	- 10 TO 0	X		X	
LINJ-4	PINTLE VALVE #4	- 10 TO 0	LVDT	- 10 TO 0	X		X	
LRCV-1	RC VALVE	-4.5 TO 4.5	LVDT	0 TO 8	X**		X	

*BASIC SAMPLING RATE 100 SAMPLES/SEC
**PARAMETER SUPERCOMMUTATED TO 1000 SAMPLES/SEC

TABLE III
NOZZLE MEASUREMENTS

Prefire Nozzle Measurements

Degrees	Throat Diameter, in.	Exit Diameter, in. (0.25 in. upstream of exit)
0	6.874	33.232
30	6.876	33.232
60	6.876	33.215
90	6.875	33.175
120	6.875	33.182
150	6.874	33.210
Average, in.	6.875	33.208
Area, sq in.	37.122	866.099
TCC-supplied area, sq in.	37.100	—

Postfire Nozzle Measurements

Degrees	Throat Diameter, in.	Exit Diameter, in. (0.25 in. upstream of exit)
0	6.851	33.500
30	6.840	33.435
60	6.841	33.425
90	6.832	33.307
120	6.848	33.436
150	6.866	33.443
Average, in.	6.846	33.424
Area, sq in.	36.810	877.418
Percent Change in Area (AEDC Measurements)	-0.8	+1.3

TABLE IV
MOTOR TEMPERATURE-CONDITIONING HISTORY

Date	Temperature, °F		Location of Motor	Relative Humidity, percent		Remarks
	High	Low		High	Low	
2/21/73	76	67	Received at X-ray	---	---	Humidity recorder malfunction at X-ray
2/22/73	79	74	X-ray			
2/23/73	80	64				
2/24/73	78	72				
2/25/73	78	76				
2/26/73	78	68				
2/27/73	65	64	Motor moved to Rocket Preparation Area	34	28	Temperature below 65°F for approximately 15 min
2/28/73	74	64		28	24	
3/1/73	74	62		33	22	
3/2/73	73	70		50	26	
3/3/73	73	71		52	44	
3/4/73	74	71		52	40	
3/5/73	73	71		54	52	
3/6/73	72	67	Motor moved to Test Cell	72	53	Motor moved to test cell
3/7/73	74	72	Test Cell	70	55	
3/8/73	73	71	Test Cell	58	52	Motor fired at grain temperature of 72°F

TABLE V
SUMMARY OF MOTOR PERFORMANCE

	ACTUAL	SPECIFICATION MINIMUM	SPECIFICATION MAXIMUM
GENERAL INFORMATION			
MOTOR S/N *	TMS-10		
MODEL NUMBER *	SR73-AJ-1		
TYPE FIRING	ALTITUDE		
DATE FIRED	03-08-73		
DATE MANUFACTURED *	09-17-69		
TOTAL MOTOR WEIGHT (PREFIRE), LBM *	8050.1		8050.0
CASE PROPELLANT WEIGHT, LBM *	7337.4		
TOTAL PROPELLANT WEIGHT (WPT), LBM *	7337.4	7290.0	
PROPELLANT SLIVER WEIGHT, LBM *	23.0		
EXPENDED PROPELLANT WEIGHT (WP), LBM	7314.4		
PREFIRE NOZZLE THROAT AREA (TCC), SQ. IN.	37.100		
PREFIRE NOZZLE THROAT AREA (AEDC), SQ. IN.	37.122		
AVERAGE NOZZLE THROAT AREA, SQ. IN. **	38.106		
POST FIRE NOZZLE THROAT AREA (AEDC), SQ. IN.	36.810		
PREFIRE NOZZLE EXIT AREA (AEDC), SQ. IN.	882.155		
POSTFIRE NOZZLE EXIT AREA (AEDC), SQ. IN.	900.150		
PREFIRE PROPELLANT GRAIN TEMPERATURE, DEGREES F.	72	65	75
AMBIENT PRESSURE PRIOR TO FIRING, PSIA	0.160		
RELATIVE HUMIDITY PRIOR TO TEST CELL EVACUATION, PERCENT	58		
TEST CELL PERFORMANCE			
ALTITUDE			
AT PRESSURANT SQUIB IGNITION, FT.	100000		
AT MOTOR IGNITION, FT	100000	100000	
AT THRUST TERMINATION, FT	101000		
AVERAGE, FT	92000	60000	
PRESSURE			
AVERAGE, PSIA	0.235		
INTEGRAL, PSIA-SEC.	14.200		
BALLISTIC PERFORMANCE			
TIME			
IGNITER IGNITION DELAY (TO 1000 PSIA), MSEC.	24		
IGNITER IGNITION INTERVAL, MSEC.	149		
IGNITION DELAY, MSEC	90		200
AT MAXIMUM CHAMBER PRESSURE, SEC.	21.980		
AT MAXIMUM VACUUM AXIAL THRUST, SEC.	21.980		
ACTION (75 PSIA CHAMBER PRESSURE), SEC.	60.490	58.20	63.14
ADJUSTED TO 70 DEG. F., SEC.	60.635		
THRUST TERMINATION (TT), SEC.	60.490		
THRUST TERMINATION FUNCTIONING, MICROSEC.			
STACK 1	403	219	705
STACK 2	438	219	705
STACK 3	473	219	705
STACK 4	420	219	705
STACK 5	455	219	705
STACK 6	508	219	705
THRUST TERMINATION INTERVAL, MICROSEC.	105		

TABLE V (Continued)

	ACTUAL	SPECIFICATION MINIMUM	SPECIFICATION MAXIMUM
PRESSURE			
MAXIMUM IGNITER, PSIA	1908		
AVERAGE IGNITER, PSIA	1763		
INTEGRAL OF IGNITER, PSIA-SEC.	264.4		
MAXIMUM CHAMBER RISE RATE, PSIA/SEC.	7370		
MAXIMUM MOTOR CHAMBER, PSIA	703		
ADJUSTED TO 70 DEG. F., PSIA	702		
AVERAGE MOTOR CHAMBER, PSIA	518		
ADJUSTED TO 70 DEG. F., PSIA	517		
MOTOR CHAMBER INTEGRAL, PSIA-SEC.	31350		
INTEGRAL OF MOTOR CHAMBER RAISED TO 0.30 POWER, PSIA-SEC.	390		
MOTOR CHAMBER AT TT TIME, PSIA	74.3	70	80
MAXIMUM FORWARD DOME CAVITY BETWEEN TT AND TT+2 SEC., PSID	0.582		0.925
AXIAL THRUST			
MAXIMUM MEASURED FORCE, LBF	46700		
MAXIMUM AUGMENTED VACUUM, LBF	46925		
MAXIMUM UNAUGMENTED VACUUM, LBF	46820		
ADJUSTED TO 70 DEG. F., LBF	46708		
AVERAGE MEASURED FORCE, LBF	34253		
AVERAGE AUGMENTED VACUUM, LBF	34462		
AVERAGE UNAUGMENTED VACUUM, LBF	34450		
ADJUSTED TO 70 DEG. F., LBF	34368		
IMPULSE			
MEASURED TOTAL, LBF-SEC.	2071952		
VACUUM TOTAL			
INCLUDING AUGMENTATION, LBF-SEC	2084608		
EXCLUDING AUGMENTATION, LBF-SEC.	2083900		
AUGMENTED VACUUM SPECIFIC			
OPTION 1 (USING WPC), LBF-SEC./LBM	282.64		
OPTION 2 (USING WP), LBF-SEC./LBM	285.00		
UNAUGMENTED VACUUM SPECIFIC			
OPTION 1 (USING WPC), LBF-SEC./LBM	282.54		
OPTION 2 (USING WP), LBF-SEC./LBM	284.90		
OPTION 3 (USING WPT), LBF-SEC./LBM	284.01	283.1	286.1
PROPELLANT FLOW RATE			
AVERAGE (USING WDOTPC), LBM/SEC.	121.93		
INTEGRAL (USING WDOTPC), LBM	7375.5		
AVERAGE (USING WDOTP), LBM/SEC.	121.30		
INTEGRAL (USING WDOTP), LBM	7337.2		
MISCELLANEOUS			
RATIO OF SPECIFIC HEAT (GAMMA) *	1.20		
CHARACTERISTIC EXHAUST VELOCITY, FT./SEC.	5212.0		

LIQUID INJECTION THRUST VECTOR CONTROL PERFORMANCE

	ACTUAL	SPECIFICATION MINIMUM	SPECIFICATION MAXIMUM
TIME			
TVC DELAY, SEC.	1.272	1.0	1.6
PRESSURE			
DURING INJECTION SURGE, PSIA	945		
AVERAGE INJECTION PRESSURE FOR 130 MILLISEC AFTER TVC DELAY, PSIA	671		
MAXIMUM INJECTANT DURING ZERO FLOW, PSIA	688		
MINIMUM INJECTANT DURING ZERO FLOW, PSIA	675		

TABLE V (Concluded)

	ACTUAL	SPECIFICATION MINIMUM	SPECIFICATION MAXIMUM
PRESSURE			
ROLL CONTROL PERFORMANCE			
ACTION TIME, SEC.	74.540		
ADJUSTED TO 60 DEG. F., SEC.	75.712		
GAS GENERATOR PRESSURE AT 13.6 SEC., PSIA	975		
GAS GENERATOR PRESSURE AT 60. SEC., PSIA	752		
MAXIMUM GAS GENERATOR PRESSURE, PSIA	1469		

* FROM MOTOR LOG BOOK

** BASED ON TCC SUPPLIED TABLE

TABLE VI
BALLISTIC PERFORMANCE SUMMARY OF LGM-30G STAGE III A&S MOTORS FIRED AT AEDC

Motor	AEDC TR Number	Date Fired	Average Altitude, ft	Motor Age, mo	Propellant Grain Temperature, °F	Ignition Delay, msec	Action Time, sec		Average FVAC		Average PC		Average CFVAC	IV, lbf-sec	ISPV, lbf-sec
							Actual	Adjusted to 70°F	Actual	Adjusted to 70°F	Actual	Adjusted to 70°F			
OPERATIONAL A & S															
AOP-1	72-168	9-6-72	90,000	24	72	108	60.42	60.57	34,527	34,444	521	519	1.739	2,086,100	284.27
AOP-2	73-23	11-14-72	92,000	24	73	98	59.44	59.65	35,064	34,938	526	524	1.749	2,084,218	283.94
STORAGE A & S															
TMS-6	71-263	9-16-71	93,000	36	73	92	60.10	60.32	34,535	34,411	519	518	1.740	2,075,549	283.92
TMS-5	72-62	2-24-72	94,000	44	72	86	60.59	60.74	34,193	34,111	519	518	1.741	2,071,726	284.11
SUR-1	72-165	8-31-72	89,000	25	71	88	63.20	63.27	32,285	32,784	491	490	1.754	2,074,547	284.20
TMS-10	73-91	3-8-73	92,000	42	72	90	60.49	60.64	34,450	34,368	518	517	1.744	2,083,900	284.01

TABLE VII
ROLL CONTROL VALVE DUTY CYCLE

Time (sec)	Valve Position
0 to 4.0	Null
4.0 to 7.0	Cw
7.0 to 8.0	10 Hz, null to Cw to null
8.0 to 9.0	10 Hz, null to Ccw to null
9.0 to 10.0	10 Hz, Cw to Ccw to Cw
10.0 to 13.0	Ccw
13.0 to 16.0	Null
16.0 to 19.0	5 Hz, null to Cw to null
19.0 to 22.0	5 Hz, null to Ccw to null
22.0 to 25.0	5 Hz, Cw to Ccw to Cw
25.0 to 28.0	Cw
28.0 to 31.0	Ccw
31.0 to 34.0	Null
34.0 to 37.0	10 Hz, null to Cw to null
37.0 to 40.0	10 Hz, null to Ccw to null
40.0 to 43.0	10 Hz, Cw to Ccw to Cw
43.0 to 46.0	Cw
46.0 to 49.0	Ccw
49.0 to 52.0	Null
52.0 to 55.0	20 Hz, null to Cw to null
55.0 to 58.0	20 Hz, null to Ccw to null
58.0 to 61.0	20 Hz, Cw to Ccw to Cw
61.0 to 64.0	Cw
64.0 to 67.0	Ccw
67.0 to 70.0	Null
70.0 to End	Cw

TABLE VIII
ROLL CONTROL SYSTEM PERFORMANCE SUMMARY

GENERAL

TEST NO.	04
DATE FIRED	03-08-73
MOTOR S/N	TMS-10
ROLL CONTROL ASSEMBLY S/N	P-0000067
TEST CONFIGURATION	ON MOTOR
ALTITUDE AT GAS GENERATOR IGNITION, FT	100,000
SYSTEM TEMP. AT GAS GENERATOR IGNITION, DEG F	72

TIMES	ACTUAL	MAXIMUM SPECIFICATION
MAXIMUM VALVE RESPONSE MSEC		
ROLL MOMENT BUILDUP		
5 HZ CW-NULL-CW	20	40
5 HZ CCW-NULL-CCW	22	40
10 HZ CW-NULL-CW	20	40
10 HZ CCW-NULL-CCW	22	40
ROLL MOMENT DECAY		
5 HZ CW-NULL-CW	18	29
5 HZ CCW-NULL-CCW	17	29
10 HZ CW-NULL-CW	18	29
10 HZ CCW-NULL-CCW	18	29
ROLL MOMENT HALF CYCLE		
5 HZ CW-NULL-CW	38	65
5 HZ CCW-NULL-CCW	39	65
10 HZ CW-NULL-CW	38	65
10 HZ CCW-NULL-CCW	40	65
ROLL MOMENT REVERSAL		
5 HZ CW-CCW-CW	24	47
10 HZ CW-CCW-CW	27	47
NULL DWELL		
5 HZ CW-NULL-CW	98	100
5 HZ CCW-NULL-CCW	97	100
10 HZ CW-NULL-CW	47	50
10 HZ CCW-NULL-CCW	47	50
COMMAND DWELL		
5 HZ CW-NULL-CW	97	100
5 HZ CCW-NULL-CCW	98	100
10 HZ CW-NULL-CW	47	50
10 HZ CCW-NULL-CCW	48	50
5 HZ CW-CCW-CW	97	100
10 HZ CW-CCW-CW	48	50

TABLE IX
THRUST VECTOR CONTROL DUTY CYCLE

Injector	Accumulated Firing Time, sec	Nominal Flow Rate, lbm/sec*
2	3 to 4	10.0
2	20 to 21	2.0
4	21 to 22	1.0
2	76 to 96	1.0

*Strontium Perchlorate

TABLE X
THRUST VECTOR CONTROL PERFORMANCE SUMMARY

NOMINAL TIME, SEC.	3-4	20-21	21-22
START TIME (CALC)	3.280	20.220	21.220
STOP TIME (CALC)	3.900	20.900	21.900
INJECTOR NUMBER	2	2	4
SPECIFIED FLOW RATE, LBM/SEC.	10.0	2.0	1.0
ACTUAL FLOW RATE, LBM/SEC.	10.2	1.99	0.97
PINTLE POSITION, MILLIINCHES	128.34	13.26	6.81
PINTLE PRESSURE, PSIA	542.	664.	668.
PROPELLANT FLOW RATE, LBM/SEC.	98	164	165
INJECTOR-TO-PROPELLANT FLOW RATE RATIO	0.104	0.012	0.006
RESULTANT YAW FORCE, LBF	1081.	435.5	246.0
UNAUGMENTED VACUUM AXIAL THRUST, LBF	27691	46629	46753
YAW-TO-AXIAL FORCE RATIO	0.0390	0.0093	0.0053
JET DEFLECTION ANGLE, DEG.	2.24	0.54	0.30
RESULTANT YAW FORCE INJECTANT SPECIFIC IMPULSE, LBF-SEC./LBM	106	219	254
AXIAL-THRUST AUGMENTATION, LBF	428.	167.8	109.8
PERCENT AXIAL-THRUST AUGMENTATION	1.55	0.36	0.23
AXIAL-THRUST AUGMENTATION INJECTANT SPECIFIC IMPULSE, LBF-SEC./LBM	41.9	84.4	113.2

APPENDIX III
INSTRUMENTATION CALIBRATIONS

Axial-Force System

The axial-force load cell is physically calibrated in the AEDC calibration laboratory before installation in the force-measuring system. An in-place, binary-step, deadweight calibrator (permanently installed and independently grounded) is used to stimulate the force-measuring system with known physical forces. The calibrator is used before a motor firing to provide an end-to-end, in-place, multiple-step deadweight calibration of the sensing, signal conditioning, and recording systems for each of the redundant axial-force measurements. The calibrator is capable of producing forces in 1000-lbf increments from 0 to 127,000 lbf. Certification is periodically conducted to determine the magnitude of the force being produced by the calibrator at various levels within its operating range and to provide traceability to the National Bureau of Standards (NBS). The uncertainty of the certification is ±0.030 percent of full scale. Estimated uncertainty of the axial-force measuring system at discrete thrust levels has been determined to be ±0.13 percent for data obtained with the digital system.

Pressure Transducers and Yaw-Force Load Cells

These instruments were physically calibrated in the AEDC calibration laboratory before installation by direct load applications. The instrumentation recording systems were calibrated at ambient conditions and, subsequently, at pressure altitude conditions using a resistance shunting method to simulate the transducer output.

Operational Pressure Transducers (OPT)

These instruments were laboratory calibrated by TCC before installation on the motor. The calibrations were transmitted to AEDC with the motor. The operational pressure transducer incorporates a one-step internal calibration shunt which produces an electrical output signal simulating a known pressure level. This signal is used to calibrate the instrumentation recording systems both at ambient and pressure altitude conditions.

Temperatures

The thermocouples were fabricated from standard thermocouple wire, the electromotive force output of which is traceable to the NBS through the wire manufacturer. The thermocouples were connected directly to a 150°F reference temperature junction and the NBS standard temperature/voltage relationships were used for conversion to engineering units. The temperature instrumentation systems were calibrated at ambient conditions and, subsequently, at pressure altitude conditions by the voltage substitution method which simulated a known input signal.

Accelerations

The accelerometers were calibrated in the AEDC calibration laboratory using an eccentric mass vibrator before installation. The recording system was calibrated by the frequency/voltage substitution technique.

Liquid-Injection Thrust Vector Control System

Relationships between injector valve pintle position transducer feedback voltage and injectant flow rate at specific supply pressure and injectant specific gravity were provided by TCC for each valve. Calibrations at AEDC consisted of a determination of the relationship between injector valve pintle position (measured physically with a dial indicator), pintle position transducer feedback voltage, and command voltage for the particular test installation. Because the pintle position transducer feedback was measured after conditioning by the AEDC system, the magnitude obtained during the AEDC calibrations was different from those provided with the TCC-supplied injector valve calibrations which presented valve position transducer feedback voltage directly. Therefore, it was necessary to establish a relationship between AEDC feedback voltage at the fully closed and fully opened positions of the valve, and linearly interpolating to obtain intermediate points. In this manner the TCC-supplied flow rate calibration data, presented as a function of valve calibration feedback voltage, were converted to flow rate versus AEDC feedback voltage for each valve (Table III-1). The instrumentation system used to record valve feedback voltage during firing was calibrated by the voltage substitution method.

TABLE III-1
INJECTOR CALIBRATION

INJECTOR SERIAL NO. HSD0131 MOTOR NO. TMS-10

INJECTOR LOCATION 90 DEGREES

PINTLE POSITION (MILLI-INCHES)	CALIBRATION VOLTAGE (MANUF)	FEEDBACK VOLTAGE (AEDC)	FLOW RATE MIL-H-5606 (GPM)	FLOW RATE MIL-H-5606 (LB/SEC)	FLOW RATE STRONTIUM (LB/SEC)	CALIBRATION SUPPLY PRESSURE (PSIA)
0.0	0.0	-0.176	0.0	0.0	0.0	645.
2.1	0.100	-0.277	1.70	0.20	0.30	645.
4.2	0.200	-0.379	3.50	0.41	0.61	640.
6.4	0.300	-0.480	5.50	0.65	0.96	641.
6.9	0.320	-0.501	5.76	0.68	1.00	641.
8.5	0.400	-0.582	7.20	0.85	1.25	638.
10.6	0.500	-0.683	8.90	1.05	1.55	636.
12.7	0.600	-0.785	10.60	1.25	1.84	635.
13.7	0.648	-0.833	11.51	1.35	2.00	631.
14.8	0.700	-0.886	12.30	1.45	2.14	633.
16.9	0.800	-0.988	14.10	1.66	2.45	631.
19.1	0.900	-1.089	15.80	1.86	2.74	630.
21.2	1.000	-1.191	17.30	2.03	3.01	622.
31.8	1.500	-1.698	23.60	2.77	4.10	608.
42.4	2.000	-2.205	30.20	3.55	5.25	598.
53.0	2.500	-2.713	35.80	4.21	6.22	590.
63.6	3.000	-3.220	40.80	4.79	7.09	578.
74.2	3.500	-3.727	45.00	5.29	7.82	567.
84.7	4.000	-4.235	48.60	5.71	8.44	555.
95.3	4.500	-4.742	51.80	6.09	9.00	546.
105.9	5.000	-5.250	54.30	6.38	9.43	538.
116.5	5.500	-5.757	57.00	6.70	9.90	527.
120.9	5.700	-5.960	57.57	6.76	10.00	525.
127.1	6.000	-6.264	58.30	6.85	10.13	522.
148.3	7.000	-7.279	62.70	7.37	10.89	508.
169.5	8.000	-8.294	65.40	7.68	11.36	498.
190.7	9.000	-9.309	67.60	7.94	11.74	487.
211.9	10.000	-10.323	69.40	8.15	12.05	479.
233.1	11.000	-11.338	71.00	8.34	12.33	475.
250.0	11.800	-12.150	71.30	8.38	12.38	472.

CALIBRATION TEMPERATURE 100 DEG F.
CALIBRATION FLUID SPECIFIC GRAVITY 0.8450
TEST FLUID SPECIFIC GRAVITY 1.850

TABLE III-1 (Concluded)

INJECTOR SERIAL NO. HSD0099 MOTOR NO. TMS-10

INJECTOR LOCATION 270 DEGREES

PINTLE POSITION (MILLI-INCHES)	CALIBRATION VOLTAGE (MANUF)	FEEDBACK VOLTAGE (AEDC)	FLOW RATE MIL-H-5606 (GPM)	FLOW RATE MIL-H-5606 (LB/SEC)	FLOW RATE STRONTIUM (LB/SEC)	CALIBRATION SUPPLY PRESSURE (PSIA)
0.0	0.0	-0.179	0.0	0.0	0.0	648.
2.1	0.100	-0.281	1.60	0.19	0.28	643.
4.2	0.200	-0.382	3.40	0.40	0.59	641.
6.3	0.300	-0.483	5.10	0.60	0.89	641.
7.1	0.340	-0.524	5.76	0.68	1.00	640.
8.4	0.400	-0.585	6.80	0.80	1.18	638.
10.5	0.500	-0.696	8.60	1.01	1.49	636.
12.6	0.600	-0.787	10.30	1.21	1.79	634.
14.4	0.685	-0.874	11.51	1.35	2.00	633.
14.7	0.700	-0.889	11.80	1.39	2.05	632.
16.8	0.800	-0.990	13.50	1.59	2.34	631.
18.9	0.900	-1.092	15.30	1.80	2.66	632.
21.0	1.000	-1.193	16.80	1.97	2.92	626.
31.5	1.500	-1.700	22.20	2.61	3.86	611.
42.0	2.000	-2.206	28.60	3.36	4.97	602.
52.5	2.500	-2.713	34.30	4.03	5.96	596.
63.0	3.000	-3.220	39.50	4.64	6.86	581.
73.5	3.500	-3.727	43.20	5.08	7.50	571.
84.0	4.000	-4.233	46.80	5.50	8.13	560.
94.5	4.500	-4.740	50.40	5.92	8.75	549.
105.0	5.000	-5.247	53.40	6.27	9.28	535.
115.5	5.500	-5.754	56.20	6.60	9.76	528.
121.4	5.780	-6.037	57.57	6.76	10.00	523.
126.1	6.000	-6.260	58.30	6.85	10.13	520.
147.1	7.000	-7.274	62.00	7.28	10.77	506.
168.1	8.000	-8.287	64.50	7.58	11.20	498.
189.1	9.000	-9.301	66.70	7.84	11.59	490.
210.1	10.000	-10.314	69.20	8.13	12.02	480.
231.1	11.000	-11.328	69.80	8.20	12.12	476.
250.0	11.900	-12.240	71.60	8.41	12.44	473.

CALIBRATION TEMPERATURE 100 DEG F.
CALIBRATION FLUID SPECIFIC GRAVITY 0.8450
TEST FLUID SPECIFIC GRAVITY 1.850

APPENDIX IV
UNCERTAINTIES OF THE J-5 INSTRUMENT SYSTEMS

1.0 INTRODUCTION

The rationale for the estimated instrument system uncertainties contained in Table IV-1 is provided in this appendix. The general approach taken in the analysis, the definition of terms, and the specific evaluation of each system are presented.

2.0 METHODOLOGY

The approach taken in this analysis follows the methodology established by the ARO Standard Test Data Measurement Uncertainty (ARO-ENGR-STD-T-4, February 1972). A review of the basic concepts and terminology is given in the following paragraphs in order to provide a better understanding of individual evaluations of the J-5 instrument systems.

The uncertainty of a measurement is defined to be the maximum difference reasonably expected between a measured value and the true value. Measurement errors have two components: fixed errors and random errors. A random error results from variations between repeated measurements and is called the precision error. The statistic, s, is an estimate of the standard deviation of a population and is called the precision index. It is calculated to estimate the precision error. The precision index is

$$s = \sqrt{\frac{\sum_{i}^{N} (x_i - \bar{x})^2}{(N - 1)}} \tag{1}$$

where

N is the number of measurements

$\bar{x}$ is the average value of the measurement

x_i is the individual measurement

The second component of a measurement error is the constant or systematic error and is known as the bias. Each measurement of repeated measurements has the same bias. Large known biases are eliminated by calibrating the instrument, i.e., comparing the instrument to a standard and obtaining a correction. Small known biases may or may not be accounted for, depending upon the significance of the bias and the difficulty of correcting for the bias. Unknown biases are not correctable. Generally, the estimate of the limit for a bias is based upon judgment and experience.

In order to establish a single number for expressing a reasonable limit for the error of a measurement, some combination of bias and precision is required. It is recognized that it is impossible to define a rigorous statistic because the bias is an upper limit based upon judgment. The uncertainty U is established as that single number for stating an error. The uncertainty is centered about the measurement and is defined as

$$U = \pm(B + t_{0.95}\, S) \tag{2}$$

where

B is the estimated bias limit

S is the precision index

t is the 95th-percentile point for the two-tailed students "t" distribution

The "t" value is a function of the number of degrees of freedom (d.f.). For 30 or more degrees of freedom, a t value of 2 is assumed.

The uncertainty is an arbitrary substitute for a statistical confidence interval and can best be interpreted as the largest error to be expected. The coverage of U is greater than 95 percent under reasonable assumptions of the distribution of the bias.

In general, the errors in a measurement process originate from a multitude of different sources. The uncertainty of a total measurement can be established by two approaches:

(a) Determining the elemental error sources in the process and appropriately combining the errors and

(b) Determining the error of the complete system by comparison with a standard.

Since the error of a measurement process is the result of elemental error sources, a methodology for combining elemental errors is required in order to arrive at the total uncertainty U.

The bias limit B in equation (2) is calculated as

$$B = \sqrt{b_1^2 + b_2^2 + b_3^2 \text{----} b_n^2} \tag{3}$$

where

b_n is the n elemental error source

The above approach is taken because it is unreasonable to assume the unknown bias limits b_n are cumulative.

The precision error S in equation (2) is

$$S = \sqrt{s_1^2 + S_2^2 + S_3^2 \cdots\cdots s_n^2} \tag{4}$$

where

s_n is the precision error in the n elemental source

The degress of freedom for S may be found by use of the Welch-Satterthwaite formula as follows:

$$\text{d.f.} = \frac{(s_1^2 + s_2^2 + s_3^2 \cdots\cdots s_n^2)^2}{\frac{s_1^4}{df_1} + \frac{s_2^4}{df_2} + \frac{s_3^4}{df_3} \cdots\cdots \frac{s_n^4}{df_n}} \tag{5}$$

The establishment of the d.f. for S makes it possible to define the precision error of subsequent measurement processes or analyses.

The uncertainties of the J-5 instrument systems are tabulated in Table IV-1.

TABLE IV-1
ESTIMATED TOTAL UNCERTAINTY (±2 SIGMA LIMITS) OF INSTRUMENT SYSTEMS USED IN DETERMINING MOTOR PERFORMANCE

	Uncertainty, percent, full scale
Pressure Measurements[1]	± 0.44
Temperature Measurements (Thermocouples, C/A)	± 0.47
Accelerations	±14.2
Axial-Force Measurements	± 0.13
Side-Force Measurements	± 0.45

[1]Uncertainty calculated for AEDC-supplied transducers only.

APPENDIX V
METHODS OF CALCULATION

The following recorded parameters were used for the calculations:

FY-1, FY-2	Measured axial force, lbf
FZA-1, FZA-2	Measured aft yaw force, lbf
FZF-1, FZF-2	Measured forward yaw force, lbf
LINJ-2, LINJ-4	Measured injector position feedback, vdc
PA-1, PA-2	Measured test cell pressure, psia
PC-1, PC-2	Measured motor chamber pressure, psia
PMI-4	Measured injectant manifold pressure

The following input constants were used:

ATI	Prefire nozzle throat area, sq in. = 37.100
C*	Characteristic exhaust velocity, ft/sec = 5212
DI	Prefire nozzle exit diameter, in. (see Table III)
EAC	Nozzle exit area erosion factor based on measured prefire and postfire areas from the Qualification Program = 1.204
SPG CAL	Specific gravity of calibration fluid = 0.845
SPG TEST	Specific gravity of injectant fluid = 1.850
WPT	Manufacturer's stated total propellant mass, lbm = 7337.4

A table of nozzle static pressure at the injector exit (PNE) versus injectant flow rate was provided by TCC.

Injectant Flow Rate, lbm/sec	PNE, psia
0	8.6
0.5	9.8
1.0	10.7
1.5	11.5
2.0	12.3
2.5	12.9
3.0	13.5
3.5	14.0
4.0	14.5
4.5	14.9
5.0	15.4
6.0	16.2
7.0	16.9
8.0	17.6
9.0	18.2
10.0	18.8
11.0	19.4
12.0	19.9
13.0	20.4
14.0	20.9

An input table was supplied by TCC to correct the nozzle throat area for the effects of erosion during motor operation. Nozzle throat areas versus time are as follows:

Time, sec	ATC, sq in.
0.0	37.100
0.2	37.170
0.4	37.238
0.6	37.308
0.8	37.377
1.0	37.443
1.5	37.618
2.0	37.704
3.0	37.795
4.0	37.861
5.0	37.914
6.0	37.956
7.0	37.994
8.0	38.024
9.0	38.044
10.0	38.065

Time, sec	ATC, sq in.
12.0	38.093
14.0	38.107
16.0	38.120
18.0	38.129
20.0	38.133
25.0	38.134
30.0	38.136
35.0	38.144
40.0	38.170
45.0	38.195
50.0	38.221
55.0	38.246
60.0	38.272
65.0	38.272

The following parameters were calculated from recorded data:

1. FA = Average measured axial thrust (parameters FY-1 and FY-2), lbf

2. PO = Average chamber pressure (parameters PC-1 and PC-2), psia

3. PALT = Average test cell pressure (parameters PA-1 and PA-2), psia

4. FTSM = Measured axial thrust smoothed by nine-point weighted average, lbf

$$FTSM_i = (FA_{(i-4)} + 2FA_{(i-3)} + 3FA_{(i-2)} + 4FA_{(i-1)} + 5FA_i + 4FA_{(i+1)} + 3FA_{(i+2)} + 2FA_{(i+3)} + FA_{(i+4)})/25$$

5. AEC = Calculated nozzle exit area, sq in.

$$AEC = AEI + (AEF - AEI) \cdot (t_i/TTT)$$

where

$$AEI = ((\sum_{i=1}^{6} DI_i/6) + 0.1247)^2 \cdot (0.7854)$$

where

$$AEF = (EAC)\ (AEI)$$

TTT = Thrust termination

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6. FTSM VAC = Vacuum-corrected smoothed measured thrust, lbf

FTSM VAC = FTSM + (PALT · AEC)

7. FZAA = Average corrected aft yaw force (parameters FZA-1 and FZA-2), lbf

8. FZFA = Average corrected forward yaw force (parameters FZF-1 and FZF-2), lbf

9. FZR = Resultant corrected yaw force, lbf

FZR = FZAA + FZFA

FZR was then corrected for null level offsets to determine FZRC

10. FPR = Thrust-to-pressure ratio, lbf/psia

FPR = FTSMVAC/PO

11. FUPR = Unaugmented thrust-to-pressure ratio, lbf/psia

FUPR = FPR corrected by straight line interpolation during periods of injection

12. FTSMU VAC = Unaugmented smoothed axial thrust, lbf

FTSMU VAC = (FUPR) · (PO)

13. DELTA FTSM = Thrust augmentation attributable to liquid injection, lbf

DELTA FTSM = FTSM VAC - FTSMU VAC

14. CFVU = Unaugmented vacuum thrust coefficient

CFVU = (FTSMUVAC)/(PO · ATC)

15. WDPTPC = Propellant mass flow rate (Option 1), lbm/sec

WDOTPC = (G · ATC · PO)/C*

16. WDOTP = Propellant mass flow rate (Option 2), lbm/sec

$$WDOTP = (WP \cdot PO \cdot ATC) / \int_{t_o}^{t_A} (PO \cdot ATC)dt$$

where

WP = WPT - 23 (sliver weight, lbm)

t_A = Motor action time

17. WDOT-I = Injectant flow rate, lbm/sec

$$WDOT\text{-}I = WDOT\ CAL \sqrt{\frac{(\Delta P\ TEST) \cdot SPG\ (TEST)}{(\Delta P\ CAL) \cdot SPG\ (CAL)}}$$

where

WDOT CAL = Input table with injectant flow rate

(WDOT CAL) as a function of injector feedback voltage (LINJ-I) and valve calibration differential pressure (ΔP CAL) (Table III-1)

ΔP TEST = (PINJ-I) - PNE

PINJ-4 = PMI-4

PINJ-2 = Surface fit with PINJ-2 as a function of PMI-4 and LINJ-2, supplied by TCC

I = 2 or 4

18. ISPSP = Axial-thrust augmentation injectant specific impulse, lbf-sec/lbm

ISPSP = FZRC/(WDOT-I)

19. RZY = Yaw-to-axial force ratio

RZY = FZRC/FTSMU VAC

20. WDOTR = Injectant-to-propellant flow rate ratio

WDOTR = (WDOT-I)/WDOTP

21. JDA = Thrust vector angle, deg

JDA = ARCTAN (RZY)

22. AAUGISP = Axial-thrust augmentation injectant specific impulse, lbf-sec/lbm

AAUGISP = (DELTA FTSM)/(WDOT-I)

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13. ABSTRACT An LGM-30G Stage III solid-propellant rocket motor, designated TMS-10 (aged 42 months), was fired in Rocket Development Test Cell (J-5), Engine Test Facility (ETF), in support of the Minuteman III Stage III Aging and Surveillance (A&S) Test Program on March 8, 1973. There was an apparent insulator/grain separation 10 sec after motor ignition as indicated by chamber pressure and linear potentiometers located on the motor aft dome and nozzle mounting flange. Vacuum thrust attained upper specification limits from 18 to 28 sec after motor ignition and was below specification limits from 46 to 54 sec. Motor ballistic, liquid-injection thrust vector control system, roll control, and thrust termination system performance was within model specification requirements. Ignition of the roll control gas generator and the liquid-injection thrust vector control isolation valve squibs was accomplished, as programmed, 2.5 sec before motor ignition at a pressure altitude of 100,000 ft. The motor was ignited at a pressure altitude of 100,000 ft. Motor ignition delay time was 90 msec. Motor thrust termination occurred at 60.49 sec at a chamber pressure of 74.3 psia. The motor produced an unaugmented vacuum total impulse of 2,083,900 lbf-sec during action time. The unaugmented vacuum specific impulse was 284.01 lbf-sec/lbm.

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